THE RISKS OF OFFSHORE OIL AND GAS EXPLORATORY DRILLING IN EASTERN CANADIAN WATERS

A Report to the Royal Commission
on the
Ocean Ranger Marine Disaster

Part One A Perspective on Risk

Part Two Risk Assessment of Human Safety

Ian Burton
Toronto
May 1984

DRAFT

THE RISKS OF OFFSHORE OIL AND GAS EXPLORATORY DRILLING IN EASTERN CANADIAN WATERS

A Report to the Royal Commission
on the
Ocean Ranger Marine Disaster

Part One A Perspective on Risk

Part Two Risk Assessment of Human Safety

Ian Burton
Toronto
May 1984

CONFIDENTIAL

DO NOT PHOTOCOPY

CAUTIONARY NOTE

This report is the property of the Royal Commission on the Ocean Ranger Marine Disaster. The contents of this report are confidential and should be treated as such. Reproduction by any means, in whole or in part, is not permitted without the written consent of the Royal Commission. The opinions, conclusions, and recommendations are those of the authors. Acceptance of this report by the Royal Commission is for contractual purposes only and should not be construed as acceptance of any of the opinions, conclusions, and recommendations contained herein.

[illegible]

[illegible]

only and should not be construed as accepta-
tion of any of the opinions, conclusions,
and recommendations contained herein.

Part One

A Perspective on Risk

Ian Burton

May 1984

Contents

I

THE PROBLEM OF RISK

For almost two decades the people of Atlantic Canada have been looking forward to the development of an offshore oil and gas industry that will bring to the region employment for the workers and a higher level of prosperity for all. It was understood from the outset that any such development involved some risk. Those who live close to the sea, and earn their livelihood from sea-going activities are no strangers to risk, and so the explorations that began in 1966 were undertaken in the knowledge that the sea is a dangerous place. Perhaps also there was some resigned or fatalistic acceptance of the risk.

Just how dangerous it can be was brought home dramatically to all Canadians on 15 February 1982 when the huge semi-submersible Ocean Ranger tilted and then capsized and sank to the bottom, with the loss of all 84 persons aboard. That event, as is a common experience following disasters, gave rise to a lot of searching questions. "Need it have happened?", "Could it have been prevented?", "How can we make sure it never happens again?" and, in terms particular to this case, "What are the risks of offshore oil and gas explorations off the coast of Canada?".

It is to this last question that this essay is addressed. Are the governments of Newfoundland and Labrador, Nova Scotia, and Canada and the people they represent sending offshore workers into situations that are too dangerous in the quest for the benefits of economic growth and development? How do we know that what governments and private corporations are asking

people to do is fair and reasonable? How can we be sure that appropriate steps have been taken to safeguard the lives of those who accept risky occupations for the benefit of the whole society?

It is not the purpose of this report to attempt definitive answers to such questions. Rather the objective in Part One is to try to clarify the concept of risk and the methods of risk analysis and risk assessment, in order to show how the problem of risk might ideally be approached. There are shortcomings in the methods and in the available data, as will be shown, but the primary aim here is to develop a reasoned approach to risk, and to place the risk of offshore oil explorations in some perspective. In Part Two an assessment of the risk is attempted, with comparisons provided of the risks of offshore drilling with other activities.

A questioning attitude to risk is a characteristic of the last decades of the twentieth century. As the second millenium draws to its close many more people are questioning, on a scale never before seen, the directions and values of western industrial society. These questions and this questioning attitude would have seemed strange to our forefathers who first settled and built Atlantic Canada. For them it was a case of "nothing ventured--nothing gained". To take risks was a way of life and while the value of skilled seamanship was a source of heroism and pride, the guidance and protection of the Hand of God was also often and earnestly sought. When things did go wrong and lives were lost people were often disposed to accept events as Acts of God and return with humility to their prayers and their boats.

What has happened to change all that? Has western society lost its nerve or its adventurous risk-taking spirit, that things are so much questioned? To the extent that this is true, it is probably due to success and affluence. The widespread concern with risk in Canada today extends to many aspects of life. Canadians are concerned about toxic contaminants in food and drinking water; about the transport of dangerous goods by road and rail; about the risks of nuclear power development; about the use of chemicals to control pests in forests and farms; and about the dangers of offshore oil and gas exploration. The list seems almost endless.

Reading our daily newspapers and watching television, a visitor from a distant country might be excused for thinking that Canada has become an extremely dangerous place where people are threatened by hazards on every side. The reverse is true. Life in Canada today is safer than it has ever been. The infant mortality rate is among the lowest in the world, and people live longer lives than in most other countries. If life is so risky, how is it that people are living longer? The truth is that life is not more risky for the average Canadian. The risks our forefathers took in developing the country, and the risks we have taken with modern technology and industry in recent decades have paid off. The wealth we have created has enabled us to reduce risks.

Of course, the type of risks we face has changed. The development of science and the application of technology have indeed created new risks that did not exist before. In general, however, the new risks have so far proved to be less serious than the old risks that we have managed to control and reduce. On balance development reduces risks. In the lives of nations as in the lives of people, richer means safer.

Paradoxically, it may be our very success in controlling risks, and guaranteeing a safer, richer and longer life for most Canadians that makes us fearful of the new and unfamiliar risks. It is not so surprising therefore that Canadians with a degree of material wealth and social security that is the envy of most of the world's people should have become fearful about the new risks they face, and even somewhat distrustful of those in authority who seek to provide reassurance and tell people that they need not be so concerned.

While it is true that Canadians are more fearful about risks than ever before, it is not always the case that those most at risk are the most concerned. Those that live close to nuclear generating stations have been shown in sample surveys to express less anxiety about the dangers of a nuclear accident than those living further away.(Whyte, 1983). Even in relation to toxic hazards, and transport risks, there is often a public interest group voicing opposition as loudly as or more loudly than those who are most at risk.(Whyte and Burton, 1982).

The concern for the dangers of offshore oil and gas explorations is another case in point. The concern for the safety of the workers, and perhaps especially for the possibility of environmental damage sometimes seems to be greater the further one gets away from the sea!

In some ways this is an encouraging sign of national maturity--when people are genuinely concerned for the welfare of all Canadians and all of the Canadian environment, wherever they may happen to live. No civilized nation in the latter part of this century would wish to be seen subjecting some of its citizens to an undue risk in order that others may benefit. The principles of fairness and equity in sharing benefits and risks have long

been established as a basis for our society, and the orderly conduct of our affairs is understood to require that all people, those with much power and responsibility, as well as those with little, approach such questions in an open-minded and reasonable fashion.

How, it might be asked, is reason to be brought to bear on such a complex matter as the risks of offshore oil and gas exploration? The answer is that new methods of analysis have been developed precisely for the purpose of handling such difficulties. Collectively called "risk assessment" these methods enable us to see what is at stake and what is involved when governments and private sector corporations embark upon new ventures in the application of science and technology for the benefit of society. This report describes some of the methods and characteristics of risk analysis especially in the context of the Eastern Canadian offshore explorations and indicates how they can be helpful now and may become more so in the future. At the outset it is also necessary to sound a note of caution. Risk analysis is not a panacea. It does not solve the problem of risk by providing a formula for decisions on the basis of quantitative analysis. What it can do is to provide perspective and facilitate choice. Ultimately the choices to be made require judgement, based on sound knowledge, sympathetic understanding, wisdom and a lot of common sense.

The beginning of wisdom in the study of risk is to realise that there is no such thing as "safe" if we mean by that some holy grail of absolute safety. Safe is a relative term. Any nation, just as any person, that is alert to the opportunities and dangers of this world, must realise that we can only hope to achieve a position that we can accept as "safe enough".

This does not mean "safe enough" for all time, but simply "safe enough" for now. What we consider tolerably safe today our children and grandchildren may not tomorrow. They will have to recognize, however, that risk is a part of life, and that living well and successfully means to choose your risks wisely. Excessive concern over the wrong risks does not lead to greater safety--it actually increases overall risk by leading to the neglect and exacerbation of other risks.

Two examples serve to illustrate the point.

Whan artificial sweeteners used in soft drinks--cyclamates--were withdrawn from the market because they were suspected of being carcinogenic, risk assessors pointed out that were consumers of soft drinks to substitute an equivalent amount of sugar in their diet, that this would contribute to obesity and heart disease. Calculations were made to show that the net effect on human health would be worse from consuming sugar than cyclamates. Thus an initial attempt at reducing risk by banning cyclamates could turn out to have quite the reverse effect.

Similarly in the case of energy production, opponents of nuclear power generation have pointed to the risk to human health of possible releases of ionizing radiation. If nuclear energy is not developed however, an expansion of fossil fuel (oil and coal) generating stations will be required with an associated increase in sulphur dioxide emissions causing acid rain. Evidence for the adverse health effects of acid rain is now beginning to appear, especially in the release of heavy metals into the environment. Here again, it is evident that well meaning attempts to reduce risk in one direction may increase them in another, and this can happen in quite unexpected ways.

In theory a balanced risk or minimum aggregate risk approach is desirable, but reliable comparisons of this kind are rarely possible. The lesson to be noted is that the apparent elimination of risks by banning cyclamates or stopping nuclear power development is not necessarily the safest course.

Not to take the risks of offshore oil and gas development could well prove to be the more risky course. But to take these risks in a careless fashion, putting those involved at too high a risk would also be, if done knowingly, an irresponsible act.

II

WHAT DO WE MEAN BY 'RISK'?

Everyone uses the word "risk" in everyday language. To develop an analytical approach, scientists have developed a more technical-sounding definition of risk. They say that risk is the probability of an event multiplied by its consequences. Or where many events are being considered, the sum of the probabilities of those events times consequences. This is written:

$$\text{Risk} = \text{Pr.(E)} \times \text{Consequences}$$

or

$$\text{Risk} = \sum (\text{Pr(E)}_i \times \text{Consequences})_i$$

Thus the risk to a pedestrian crossing the road is the probability that he or she will be hit by an automobile times the consequences of such an accident. Let us assume that one accident takes place for every million pedestrian road crossings. Then the risk of crossing the road is 10^{-6} x the consequences of the accident. Let us further suppose that for every ten such accidents, 9 result in injury to the pedestrian and 1 results in the death of the pedestrian. Then the probability of a person being injured when crossing the road is .000 000 9. And the probability of being killed is .000 000 1, or one chance in ten million.

Note that a risk always has four components--the probability of an event occurring; the time span or conditions under which it can occur; its

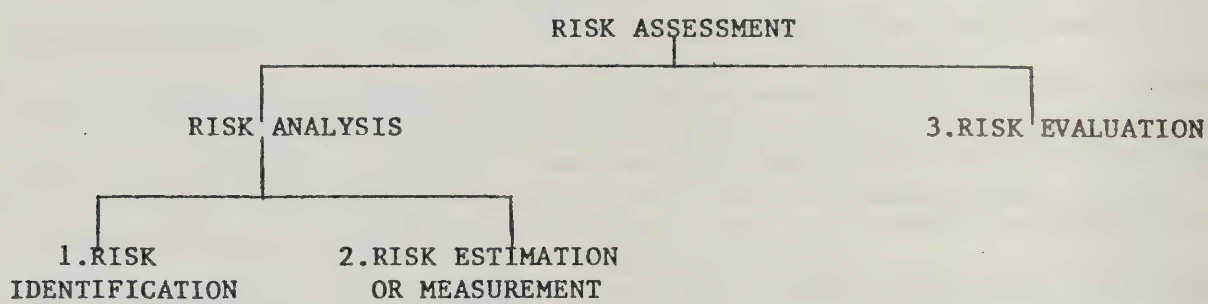
consequences; and a decision by some person or group to take the risk. A person is only at risk while actually crossing the road. In theory there is often a way to eliminate the risk altogether. In this case, as in many others, a decision never to cross the road sounds rather impractical.

A hazard is not exactly the same thing as a risk. Any automobile travelling along a highway is a hazard. Swamps, poisonous snakes and tornadoes are also hazards. The most effective way of reducing the risk posed by these hazards is to stay away from the places where they exist or are apt to occur. Stay off the road, away from the swamp, away from snakes and keep out of tornadoes. Such advice is not always practicable. Roads must be crossed, and large tracts of high quality agricultural land lied in the "tornado belt" of the mid-west. Where chance or necessity or the search for economic gain bring human activity into contact with hazards some risk exists. The choice of human activity and its location is therefore as much a cause of risk as the hazards themselves. Icebergs travelling down the east coast of Canada, and the storms and the cold water are all hazards. The risks are created when the economic benefits to be gained from offshore oil explorations lead people to place themselves and their technology in the path of icebergs and storms. (Burton, Kates and White, 1978).

Safety is but the corollary of risk. Where risk is high, conditions may be said to be unsafe. It should be noted that in practical terms the focus on safety is somewhat different from a focus on risk. Those whose point of departure is safety are usually concerned to improve safety. It is almost axiomatic among safety experts that things are not safe enough and that safety should be improved.

While such a compelling view is hard to resist, the point of departure for risk analysis is somewhat different. The risk analyst asks, "What is the actual level of risk?". Only when this question has been answered does the risk analyst go on to ask, "And is that level of risk acceptable or tolerable or must something more be done about it?".

Risk assessment may be thought of as consisting of three separate processes. These are: risk identification, estimation and evaluation. Risk identification and estimation can be approached in a scientific manner and to some extent expressed quantitatively. Risk evaluation is the social process of attempting to make a decision about risks--are they acceptable? Should the risk-generating activity be undertaken and if so under what terms and conditions?



It should not be thought that identification--estimation--evaluation is a straightforward linear process moving in one direction only. Sometimes preliminary evaluations of risk have to be made before we are confident about their magnitude or even their existence. Sometimes, as in the case of some organo-chlorine pesticides we think that there <u>may</u> be a risk and decide to "play it safe" by banning or restricting their use before all the evidence is in. In other circumstances we may not even have thought of the

risk until the consequences are observed--fish or birds are killed or an accident happens and people die. Then we realise that some mistake has been made and we start a search for the cause.

Once risks have been identified, estimated and evaluated there remains the all important task of risk reduction or risk management. While it is beyond the scope of this report to go into detail about risk management, no discussion of risk assessment would be fully satisfactory without some mention of its use in risk management. This is addressed in Section VIII below.

III

THE ANALYSIS OF RISK

There are three approaches to the analysis of risk. These are briefly, the method of historical analysis or going by past experience; the method of transfer of experience from similar circumstances; and thirdly a risk modelling approach. Each of these is described in some detail.

1. Historical analysis, or let experience be your guide.

Many risks are not new. They have existed in more or less the same form for many years. In such cases there are often accident records or similar data that permit calculations to be made of the frequency of adverse consequences of various kinds resulting from the probability of events, over a specified period of time or exposure.

This approach is rather like that of the epidemiologist looking for the incidence and then the causes of human disease. The number of injuries and fatalities is observed, and the incidence calculated in relation to time of exposure. In the case of human safety in the eastern Canada offshore exploratory drilling operations it is necessary to know how many disabling accidents occur and how many fatalities, in relation to the total number of person/months or years spent in this activity. Further information on how these occur and under what circumstances is required to make a diagnosis.

This method of risk analysis is the most used, and is a well-established statistical approach. It has two major deficiencies,

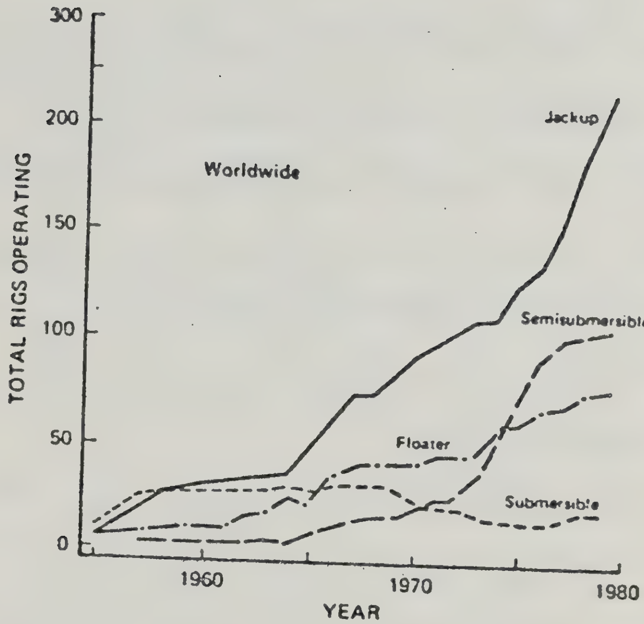
however. In the first place the necessary data to make reliable, reasonably accurate risk estimates may be lacking. As is shown later, this is regrettably the case in the Eastern Canada offshore area. Some of the needed data are not available, and what data do exist are subject to serious qualifications.

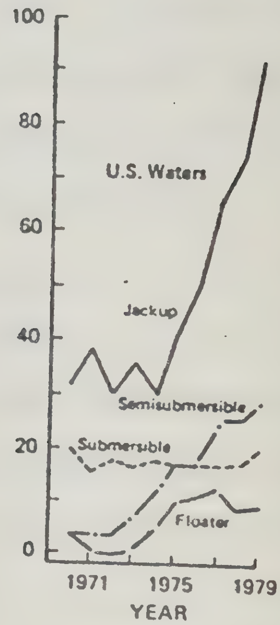
The second major deficiency of the historical-epidemiological approach is that the past record of safety may not be a reliable guide to the future. This is especially so when the technology being employed is new or is being rapidly changed. Although offshore oil drilling has been taking place for more than 80 years since the first wells were sunk off wooden piers extended out into the Gulf of Mexico, the industry has grown very rapidly since the mid-1960's as shown in Figure 1.

In 1979 there was a fleet of 450 mobile offshore drilling units (MODU's) world wide, and of these, 148 were in U.S. waters and 10 in the Eastern Canada region for at least part of the year. Many of these MODU's incorporate new design features and are larger in size than previous models. The bigger the MODU and the more men on board the greater the possible consequences of a severe accident or total loss. The more effective the new design features the more reliable the MODU's are likely to be. For these reasons the historical record may be an unreliable guide for what to expect in the future. Generally speaking as technology advances and as improvements are made in the light of experience, the safety record steadily improves. At the same time the larger scale of operations opens the door to the possibility of larger scale catastrophes. The informed judgement of experts may be used to assign relative weights to these

FIGURE 1

GROWTH OF THE WORLDWIDE AND U.S. MODU FLEET





Worldwide - Modified after Huff, John R., "Study Analyzes Offshore Rig Casualties," Oil and Gas Journal, Vol. 74, November 29, 1976.

U.S. Waters - Committee on Assessment of Safety of OCS Activities; data from Offshore Rig Data Services, Inc.

Source: U.S. NAS Report, p.203

factors. The historical record by itself is not necessarily a good guide to the future.

2. <u>The Transfer of Experience, or let someone else's experience be your guide.</u>

In situations like the Eastern Canada offshore oil exploration there is a more fundamental limitation to the historical approach. Offshore drilling only began in 1966 and up to 1983 there have been a total of only 49 rig-years of drilling experience. The record is too short to provide a reliable sample of time from which to estimate risk, especially for those events that occur with low frequency. In these circumstances one can transfer the experience gained elsewhere and apply it with any necessary changes to the new location.

Is it reasonable to suppose that the risks of offshore oil and gas explorations in the Atlantic off Canada's east coast are more risky or less risky than similar activities in the Gulf of Mexico, the California coast, the North Sea or elsewhere in the world?

Here again, there are factors which point in both directions and where expert judgement might be used. Canada, coming late into the offshore game, benefits from the learning elsewhere. The evidence shows that the accident rate among the world-wide fleet has gone steadily down. (See Table 1). Since the period 1956-60 total loss rig accidents have declined from 7 out of 327 rig years (2.2%) to 63 out of 5,125 rig years (1.2%) in the period 1976-80.

TABLE 1

TOTAL LOSS ACCIDENTS PER RIG YEARS

Rig Years / Accidents

	1956-60	61-65	66-70	71-75	76-80	Totals	Percent Ratio
Submersibles	128/1	143/0	139/0	101/1	98/0	609/2	.33%
Jackups	118/5	208/6	445/8	639/12	1041/16	2451/47	1.9%
Barges	57/1	87/2	124/1	137/2	142/0	547/6	1.19%
Drillships	16/0	42/0	95/0	144/0	268/0	565/0	0.*
Semi-Submersibles	8/0	18/2	99/1	250/1	578/4	953/8	.84%
Totals	327/7	498/10	902/10	1271/16	2127/20	5125/63	
Percent Ratio Per Total Rig Year Period	2.2%	2.0%	1.1%	1.3%	0.9%	1.2%	
Cumulative Percent Ratio		2.1%	1.6%	1.4%	1.2%		

* The drillship Glomar Java Sea was lost in the China Sea in 1983.

Source: Offshore Rig Data Services, Research and Consulting Division, 1983. Accidents: Offshore Mobile Drilling Rigs 1955 to Present. Houston, Texas.

On the other hand, Canadian offshore waters are different from other parts of the world. The sea can be very stormy indeed. It is true that hurricanes are a problem in the Gulf of Mexico, but the temperature of the air and the sea are not so cold. In the North Sea heavy storms do occur, and in the northern North Sea at least, the temperatures of air and sea are also very low. Icebergs are a more frequent danger in the western Atlantic region than anywhere else in the world.

These considerations do not mean that experience elsewhere is of no help in assessing the Eastern Canada offshore risk, but simply that the data and the estimates have to be treated with caution and some allowances made for the differences in both directions.

3. Risk Modelling, or let theory be your guide.

In response to the recognized deficiences of the historical approach to risk, or letting experience elsewhere serve as a guide, some new methods have been developed all of which are variations of theoretical model building.

This approach to risk analysis was first fully developed under the U.S. National Aeronautics and Space Administration (NASA) in connection with space flights and the Moon landing. Here was a case where the historical record was of no help whatsoever! Nor was the experience of the U.S.S.R. helpful because the designs were different and secrecy prevented access in any case. At the same time it was considered to be vitally important that the space missions succeed, both for the safety of the crews and for the continuance of the space programme.

Detailed models of the rocket-satellite-orbit and recovery process were developed. These are not physical models, but diagrams and equations on paper which describe each component and each link in the process. Two modes of analysis are applied, called fault-tree and event-tree analysis. The major difference between these approaches is simply one of direction of search. In fault-tree analysis, a fault--any fault--is postulated. Then the possible causes of such a fault are "imagined" by asking in as rigorous a fashion as possible what could have been the cause.

For example, if a car won't start, the mechanic begins by examining several possible immediate causes--the battery is dead, the points are damp, the spark plugs are not working and so on. Each of these immediate and proximate causes has its own set of possible causes. In this way a branching fault-tree is contructed working "upstream" away from the fault.

Fault-tree analysis can be used to make design improvements by discovering how faults may arise and taking preventative steps. Fault-trees may also be used to estimate probabilities of failure by attaching probabilities to each step in a causal chain.

This leads to event-tree analysis, in which an initiating event is postulated and the model is developed in a "downstream" direction by asking what the possible consequences of an initiating event could be. Again a branching network is developed working away from the initial event.

The actual and realistic specification of event-trees is a very complex and time consuming process. Carried out thoroughly there are many possible branches of the tree. At each step along the consequence chain the number of possibilities increases. The risk analyst may then estimate the

probability of the chains of alternative consequences of the initiating event.

An example of a simplified event-tree for a large loss of coolant accident in a nuclear power station is shown in Figure 2. In this model the initiating event is a pipe break in the primary system of the reactor. The tree is developed by determining, from an intimate working knowledge of the reactor, what other systems might be affected in the subsequent course of events. In the example in Figure 2 the main questions being asked are:

Will the station's own supply of electric power fail?

Will the ECCS (emergency core cooling system) fail?

Will fission product removal fail?

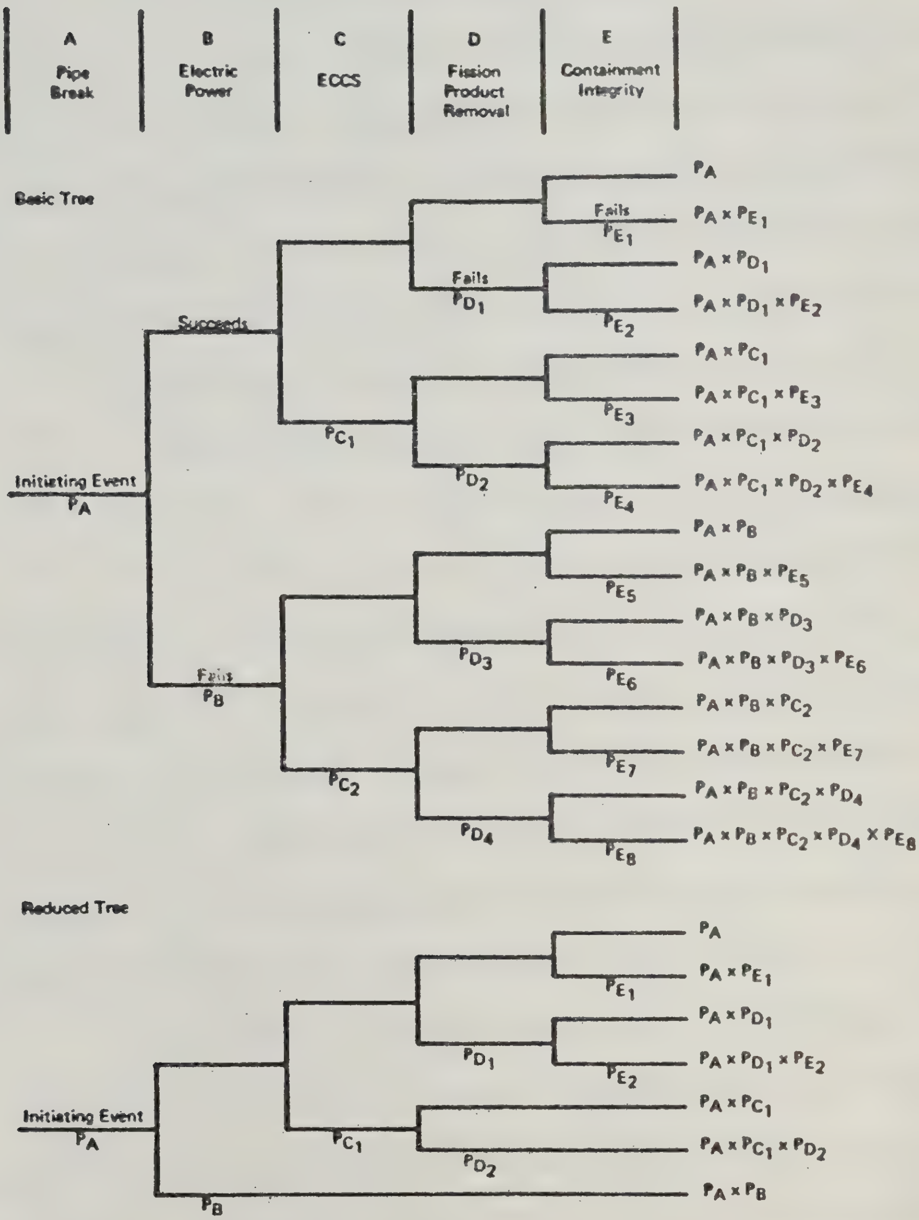
Will containment integrity fail?

The systems are ordered in the time sequence in which they are expected to affect the course of events. For the initiating event a probability of its occurrence is estimated. How often can such pipe breaks be expected to occur? This is obtained by experience in the use of pipes in non-nuclear systems. For each of the succeeding events the probability of the system to perform its function (probability of success) is estimated as well as the probability of failure to perform its function.

The upper portion of Figure 2 shows a set of theoretical paths. In practice, as shown in the lower part of the figure many of these paths can be eliminated because they represent illogical sequences. If the event-tree is properly constructed (the example here is greatly simplified) the series of events in each accident chain or sequence is defined so that it is possible to calculate the probability of consequences for that series.

FIGURE 2

SIMPLIFIED EVENT TREES FOR A LARGE LOSS OF COOLANT ACCIDENT



Note - Since the probability of failure, P, is generally less than 0.1, the probability of success (1-P) is always close to 1. Thus, the probability associated with the upper (success) branches in the tree is assumed to be 1.

Source: U.S. Atomic Agency Commission (1974) Reactor Safety Study (WASH 1400), Washington, D.C.,p.89.

In Figure 2 the event-tree has been generalized into major systems components. This is called a top-level event-tree.

The human imagination is an important limiting factor in this type of analysis. In order to be modelled and estimated an accident sequence has to be thought of. Experience shows that accident sequences not previously imagined in detail by anyone have a nasty habit of occurring. The explanation is that in complex and large scale technology or engineered systems things can go wrong in so many different ways that it is not possible to imagine them all in advance.

A classical example is the fire at the Brown's Ferry nuclear reactor in Alabama. Two men were testing the flow of air in a ventilation shaft with a lighted candle. This is a normal procedure. The candle accidentally ignited some insulation material around the electrical system. Under such circumstances the rules of procedure call for those on the scene of the fire to give the alarm immediately. However the workmen were embarrassed at what they had done and instead tried fruitlessly to put out the fire. When they finally did give the alarm half an hour later the fire had spread much further into the insulating material. As it happens the fire was brought under control without disastrous consequences. The example makes the point that all possible accident sequences are impossible to imagine in advance.

Risk modelling, and event- and fault-tree analysis first came to widespread public attention in the application of the methodology to nuclear generating stations in the so-called Rasmussen Report. (U.S. Atomic Energy Commission, 1974). The success that such methods enjoyed in space technology were not replicated, however, in the case of nuclear technology.

The Rasmussen Report, (U.S. Atomic Energy Commission 1974) claimed to show that the probability of a major reactor incident was very low, in the order of one in a million reactor/years. Critics faulted the methodology on many counts, and charged that the motivation or the intended effect of the study was to show that the risks were very low, rather than to improve safety.

IV

METHODS USED IN THIS STUDY

The three methods described--historical analysis, transfer of experience and risk modelling are not mutually exclusive. Any combination of them may be used. Risk modelling is substantially more expensive and time-consuming than the other two however, and for this reason it has been little used in the offshore oil and gas industry. The best developed examples of risk modelling are by Det Norshe Veritas of Norway and the Royal Norwegian Council for Scientific and Industrial Research in the North Sea (Jensen, Vedeler and Wulff 1979).

The terms of reference of the present study are confined to historical analysis and the transfer or comparison of experience elsewhere. The short period in which offshore oil explorations have been conducted in eastern Canada severely limit the inferences that can be made from historical data analysis. Comparisons have been made with estimates from world-wide data and from other regions--e.g. the U.S. offshore and the North Sea region including British and Norwegian waters.

It is of course practicable to carry out a risk modelling study for the eastern Canada offshore area given sufficient time and money. Considering the cost, however, and the limitations of this method, and the relatively small scale of the Canadian industry to date, it seems more sensible to use the simpler and less costly methods first and then to decide what further analysis is needed and justified.

V

RISK EVALUATION

Once actual levels of risk have been measured there remains the crucial task of evaluation. The evaluation of risk is part of the management process in which many decision-makers are involved at different levels. Those who have to decide about risk in this case include the following:

i) the oil and gas industry companies including the owners of MODU's, and the petroleum production companies;

ii) the workers who accept jobs in the offshore industry;

iii) the companies and their workers who supply and maintain the exploratory drilling operations, including the use of supply vessels and helicopters;

iv) the immediate families and friends and local communities from which some of the offshore workers are recruited;

v) the provincial authorities, in this case of Newfoundland and Labrador, and Nova Scotia, which oversee certain aspects of the offshore industry and have a responsibility to ensure the adequate safety and where necessary compensation for injury among the workers;

vi) the federal authorities which regulate certain aspects of the offshore industry, and have a responsibility in the search and rescue field. The federal authorities also have a responsibility at the international level to protect and

safeguard the offshore oil and gas industry and its employees in the national interest.

Each of these groups has its own perspective on the offshore oil and gas industry, and each has its own view of risk. The skill required of decision-makers in this situation is considerable. What they must do is attempt to work harmoniously and effectively with each other recognizing that perceptions of risk vary according to the position one occupies and the responsibilities one bears.

This paper is concerned to point out some of the principal ways of risk evaluation and to show how these are effected by risk perceptions.

1. Real Risk versus Perceived Risk

There is a tendency among scientific risk analysts to assume that measured risk is "real" whereas the perception of risk adopted by others such as those at risk or the lay public at large is somehow unreal or distorted.

In fact both points of view are risk perceptions. The scientific risk analyst attempts to be objective in his analysis and claims "rationality" because his observations are measured and the measurements can be tested and replicated by others. The perception of those at risk and of the lay public is seen as subjective because it tends to involve an emotional or less dispassionate component. This emotional element is often expressed as a value judgement or a preference about which people feel strongly.(Whyte, 1983).

What is less readily appreciated is that objective methods of risk analysis also carry with them value judgements often in a concealed way.

For example, the results of a risk analysis are commonly expressed in terms of expected fatalities or injuries per unit time of exposure. Thus (to cite one such estimate from Norway) the chance of death to an offshore worker on a drilling platform is between 1.7 and 2.8 per 1,000 man years or a probability of death in a given year of work of from .0017 to .0028. From such estimates, and depending on the total size of the workforce, it is possible to calculate the average annual number of expected deaths. Such macabre arithmetic reduces the horror of accidental death to probabilities and average annual expected values of non-identifiable people. These are "statistical" deaths.(Jensen, Vedeler and Wulff, 1979).

From the point of view of those at risk, however, and their immediate families, the question is not one of probabilities but one of life or not life. "Will my rig be safe?" For those that lose their lives the fatality rate is not .001 but 100%.

When accidents occur they are sometimes large. So the pattern of fatalities is not the loss of an "expected value" number of lives per year, but some, perhaps many, years with no loss of life and occasional years with major disasters. To those at risk and to the lay public the shock, the stress and the anxiety created by a major disaster is a far more powerful consideration than the probability of average annual fatalities. So the public perception tends much more to emphasize the need to avoid catastrophes, and is much less concerned with probabilities. Both are valid perspectives and both have to be taken into consideration by decision-makers.

2. Acceptable Risk versus Tolerable Risk

Much of the attention given to risk evaluation centres on the question of the amount or level of risk that may be acceptable. A variety of decision criteria are proposed to help determine acceptable levels of risk. A particular difficulty is that levels of risk are often unequally distributed and that the distribution of risk does not correspond to the distribution of benefits.

A critical question for risk management then becomes "acceptable to whom?". Social conflict situations arise in which a few are asked to bear a higher level of risk for the benefit of a larger number. Resolution of such conflicts can be achieved if it is understood that adequate compensation has been paid to those who face higher risks for the general good, and if it is understood that such risks are not accepted for all time, but are only "tolerated".

The fact that workers accept employment on offshore drilling units at a given compensation level does not mean that further efforts to reduce risk are not in order.(Kasperson and Kasperson, 1983).

VI

RISK COMPARISONS

A common approach to risk evaluation is to compare one set of risks with another. Four comparisons are often made--with natural or background levels, with risk of alternatives, with other unrelated risks and with benefits.

1. Comparison with natural or background level--incremental risk.

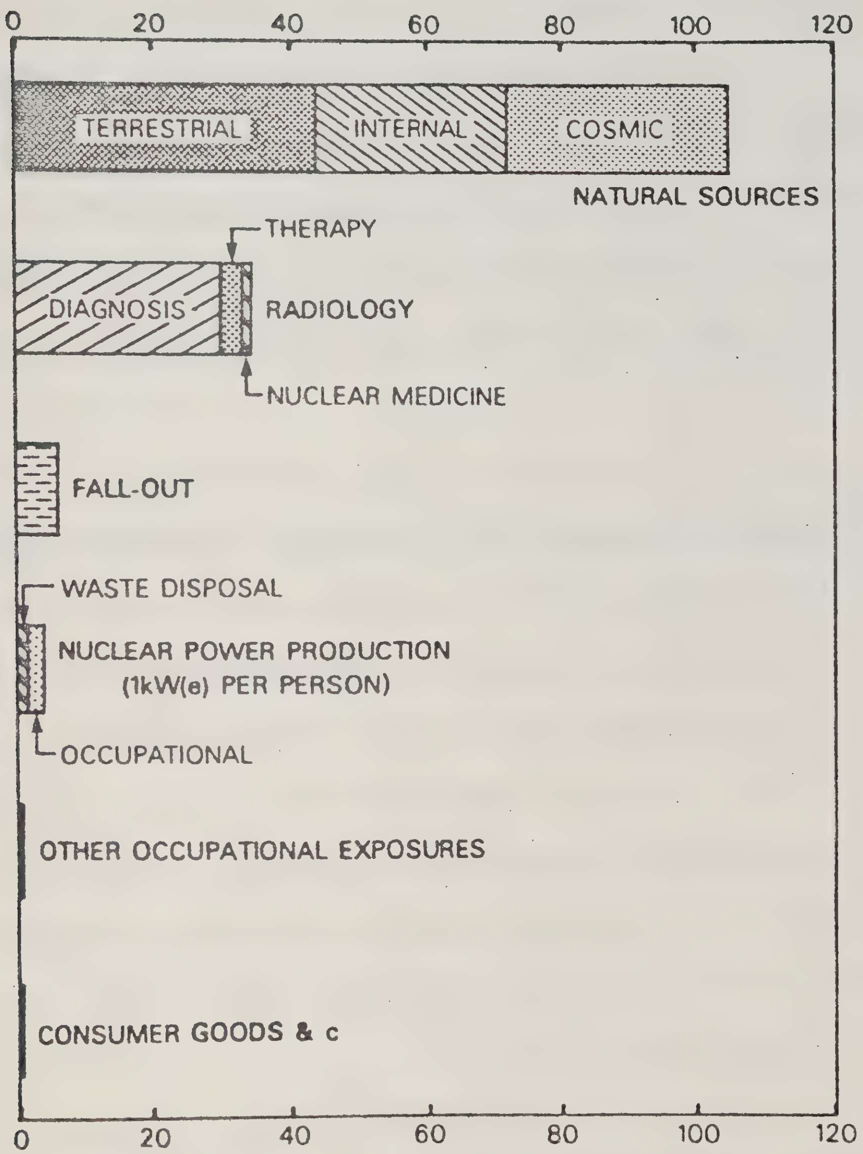
Any new risk imposed upon society or a segment of the Canadian public may be compared with the pre-existing level of risk. The rationale behind such comparisons is usually to be able to show that the new risk represents only a very small increment on top of a pre-existing level of risk. Thus in Figure 3 the increment in the exposure to radiation from nuclear power generation is much smaller than the increment in exposure from medical treatment and diagnostic examinations, and both are smaller compared with natural background levels. The implication of this comparison is that there should be no cause for alarm when the incremental risk is so small.

While this argument appears sensible and persuasive to many managers of nuclear risk, it is less so to those who are at risk. Why bear or accept any additional increment of risk unless there is some compelling reason to do so?

In the case of off-shore drilling there is no equivalent of natural or background levels so such a comparison is not possible in any case.

FIGURE 3

ANNUAL GENETICALLY SIGNIFICANT DOSE RATE



Source: A.M. Aiken, J.M. Harrison and F.K. Hare, 1977 <u>The Management of Canada's Nuclear Wastes</u>, Report EP 77-6, p.28.

2. Comparison with risks of alternatives--there's a better way.

Another sort of comparison may be made with the risks of alternative ways of achieving the same end. Thus the electric power generated by nuclear stations may be produced in other ways (by coal or oil-fired generating stations, by hydro-electric power and so on). Comparisons of the risk per kilowat hour of electricity production may be used to show that one form of production is less risky than another (Inhaber, 1978).

In the case of offshore oil and gas exploration, comparisons may be made with onshore exploration or with other energy producing activities e.g. coal mining.

3. Comparison with other unrelated risks--it's safer than smoking.

A third type of risk comparison examines risks in one activity in relation to other activities that are not alternatives but are totally unrelated. A favourite comparison is with cigarette smoking. Cigarette smoking may be shown to be more hazardous than many other risk-taking activities. The implication here is that if people are prepared to accept the risks of smoking then logically they have no reason to object to activities which produce much lower risks e.g. nuclear power generation or off-shore oil and gas explorations.

Neither comparisons with alternatives, nor with non-related risks provide an adequate basis for accepting risk. They are, in fact, forms of risk rationalizing. From the perspective of those at risk as well as society as a whole there is no justification for accepting additional risks, however small unless this is a wholly voluntary choice as in the decision to

canoe, climb mountains, or smoke cigarettes. Where there is an element of imposed risk, then it must be shown that there are benefits that justify the risk.

4. <u>Comparison with benefits--the risk is worth it.</u>

Comparison of risks with benefits is a more valid criterion for risk evaluation. Correctly speaking there are three elements in the comparison--costs, benefits, and risks. For a given project or activity, the preferred alternative may be specified as that which maximizes net benefits at least risk.

For example, a comparison might be made between electricity generation by oil and by tidal power. Offshore oil explorations and development might be compared with Bay of Fundy tidal power. The analysis would include estimates of benefits as measured in the value of the power to be produced, less the costs of developing the power, examined in the context of a statement of degree of risk involved in each venture.

It is conceivable that in certain instances the risks involved might be judged too high in relation to the net benefits.

VII

THE ECONOMICS OF RISK REDUCTION - OR WHERE IS THE STOPPING POINT?

In all human designed systems the degree of safety can be increased by further expenditures of funds. This usually involves the strategy against failure that may be described as "defence in depth". Extra design features and back-up systems are provided to prevent failure or to operate should the normal control mechanisms fail. In theory there is virtually no stopping point in this process. Extra safety margins can always be allowed in design and extra fail-safe back-up control systems provided. At some point a decision has to be made which involves a trade-off between safety and cost.

If the cost of making a system safe enough is so high that it absorbs all or most of the profitability or benefit from the system then it is probably too risky. Tolerable levels of risk, and acceptable levels of profit or benefit are not fixed quantities, and both may change according to circumstances. While in theory an objective of maximizing benefits over risks may be ideal, in practice some rule-of-thumb judgements have to be made.

In relation to offshore oil worker safety the question may be put in the following terms--"for any given option that will reduce risks, what is the expected cost and what will this achieve in terms of accidents and fatalities prevented?". In order to answer such questions and to make the difficult value judgements required it is essential to know existing accident rates and fatality rates and to be in a position to assess their causes. Unfortunately, calculations of accident rates on the basis of a

short period of record are statistically dubious. A first priority for rational decision-making concerning further expenditures on risk reduction is an adequate data-base from which to specify the actual level of risk.

In the absence of such data, inferences can be drawn from what is known about existing risk levels in the offshore industry elsewhere in the world. As is shown in Part Two of this report, there is evidence from other countries that the level of risk to employees in the offshore oil industry is no greater, and probably less than the risk in comparable industries onshore. This appears to be most likely for normal workplace or industrial hazards. It may not be valid for the category of marine disasters in which a whole rig is lost. Such events (like the loss of a ship at sea) are relatively rare (perhaps once for every 80 rig-years of operation on the average.)

VIII

RISK MANAGEMENT

The purpose of risk assessment is to provide an input to the decision-making process that may be called risk management.

Broadly speaking there are two directions in which risks may be reduced. By the better design and operation of systems the probability of accidents or accident sequences can be reduced. Recognizing that accidents cannot be altogether eliminated efforts can be made at the mitigation of consequences.

Prevention of accidents can be achieved by improved designs. The methods of risk modelling can be used to detect possible accident sequences and lead to suggestions for prevention.

Many accidents are caused by the use of improper procedures or by the failure to apply standard procedures promptly and effectively. The problem can be approached by the establishment of detailed rules of procedure by a regulating agency followed up with sufficiently frequent inspections to ensure that the procedures are followed. Ironically too heavy an emphasis on regulations can in fact lead to a neglect of rather obvious safety precautions. In risk management as in other fields there are dangers associated with over-regulation.

An important antidote is manpower training. Experience in the oil and gas industry and in many other places shows that accidents are often caused by inexperienced or poorly trained manpower.

Consequence mitigation is a generally neglected area of risk management. Given that all accidents cannot be prevented emergency preparations are required to ensure that when disasters do occur they can be contained as rapidly as possible and the consequences averted or limited.

Risk analysis and risk assessment are in their present guise, new analytical approaches to the social problem of risk. The applications of the approaches, their concepts and methods in the management of risk is a recent development. Under the circumstances it is to be expected that while social learning takes place there will be some confusion and uncertainty about what is happening, and some mistrust among the participants. This essay is an attempt to help dispel confusion and mistrust, and to promote the effort to light candles rather than curse the darkness.

Part Two

Risk Assessment of Human Safety

Ian Burton

Dennis Fortune

May 1984

ACKNOWLEDGEMENTS

We are grateful to the staff of the Royal Commission on the Ocean Ranger Marine Disaster who provided information and opinion on many aspects of offshore safety. In particular, the librarian, Mrs. Heddie Peddle, was tireless in her efforts to help us ferret out data.

Others who assisted us include:

H.R. Gill, Worker's Compensation Board of Nova Scotia

John Paterson, Department of Labour and Manpower, Nova Scotia

Carol MacCulloch, Department of Development, Nova Scotia

Frank Butler, Department of Labour and Manpower, Newfoundland and Labrador

Charlene Pecklan,Department of Labour and Manpower, Newfoundland and Labrador

Christopher J. Noll, Petroleum Directorate, Newfoundland and Labrador

John Bambrick, Worker's Compensation Board of Newfoundland and Labrador

Merv. Andrews, Worker's Compensation Board of Newfoundland and Labrador

Ted Starr, Canada Oil and Gas Lands Administration

Hector Ewing, Canada Oil and Gas Lands Administration

We also acknowledge advice and suggestions from Omand Solandt and Ernest Siddall.

Critical comments on a draft of the report were made by:

Bevin R. LeDrew, Director of Studies, and R.G. Dyck, Studies Manager, (both of the Royal Commission on the Ocean Ranger Marine Disaster;

by Mr. A.A. Bruneau of Bruneau Resources Management Ltd., St. Johns', Nfld.;

by Det Norske Veritas (Canada) Ltd. of Calgary (J.E. Hagen, President); and by B.P.M. Sharples of Noble, Denton and Associates Inc. of Houston, Texas.

The authors alone are responsible for the opinions and judgements expressed and we alone are responsible for errors of fact and omissions.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

I

OBJECTIVES AND LIMITATIONS

The purpose of this report is to provide an assessment of the risk to people engaged in the offshore drilling operations being conducted in the Eastern Canadian continental shelf area. The study is not concerned with economic risks, such as the possibility of economic loss by damage to or complete destruction of equipment. Nor is the study concerned with the health of offshore workers as it might be affected in the long term by the nature of the workplace environment. Nor is the study concerned with effects that might cause damage to the natural environment such as fisheries or marine ecosystems through oil spills. The study is concerned solely with the risk of accidents that might result in injury or death to offshore workers.

The study seeks answers to two rather straightforward questions.

1. When a person accepts a job in the exploratory drilling for oil and gas in the Eastern Canada offshore area, what chances of fatality or injury is he/she taking?
2. How does this level of risk compare with that elsewhere such as in land-based industry, other marine occupations, or offshore oil and gas explorations elsewhere in the world?

The analysis which follows shows that while there are undoubted risks to human safety in offshore drilling there is no evidence to show that they are worse in eastern Canada than elsewhere in the world, and the risks in

the offshore oil industry in other parts of the world appear to be no worse than in other industrial occupations. These conclusions hold provided that the major disasters such as the loss of the Ocean Ranger and the Alexander Kielland are excluded from the statistics.

More importantly these conclusions have to be seen in the light of data availability and for this reason the limitations of the analysis are emphasized by making them clear at the outset of the report. The limitations are of three main kinds--the lack of experience, the unreliability of data and the lack of analysis based on risk modelling.

In Part One of this report the methods of historical analysis, transfer of experience and risk modelling have been described. The limitations of these methods in their application to the study area must be recognized.

1. <u>Lack of experience</u>

Although the offshore oil and gas industry extends back for several decades in the Gulf of Mexico, its spectacular world-wide growth has been a phenomenon of the late 1960's and the 1970's. During this time the technology of offshore drilling has been changing rapidly, and the size of the drilling units have been dramatically increased. There has been relatively little time for experience to accumulate about accident rates and fatality rates, and what experience there is may not be a good guide to the future because much of it has involved different technology and has taken place in different marine environments.

The problem of lack of experience on a world-wide basis occurs in extreme form in the study area. The total service of MODU's world-wide is less than 5,000 rig-years. In the eastern Canada offshore area the total is less than 50 rig-years altogether up to the end of 1983 (The estimate is 48.3 rig-years). This is far too short a period of record for the reliable estimation of the frequency of accidents, especially of the more rare events, on an historical basis.

2. Unreliability of data

The data that do exist for the short period of record are neither complete nor reliable. Proper estimation of risk requires complete data on injuries and fatalities, and on "exposure levels" or time at risk. The record of fatalities and injuries provides a measure of consequences, and the population of the workforce or person/years permits a calculation to be made of rates or probability per unit time of exposure.

Canadian data

The main source of data for Canada is at the provincial level. For example, since 1980 accident statistics for exploratory drilling operations off Newfoundland and Labrador, have been reported to the Provincial Petroleum Directorate. Monthly accident reports are submitted to the Directorate by the oil companies. The monthly tabulations are provided with the following headings:

--number of lost time accidents, differentiated for local and expatriate workers;

--person/hours worked;

--frequency rates, including drilling unit rate, oil company rate, and industry-wide rate for both Canada and the U.S.A.;

--cumulated frequency rate for the year to date.

Examination of the reports reveals that the lost time accident column appears to be the only one consistently filled in. A lost time accident (or disabling injury) is one in which the worker is not able to continue working or is unable to return to work for the next scheduled shift.

Data on person/hours worked are incomplete or often lacking altogether. Thus no calculations of accident rates and no measure of safety performance is possible on the basis of accident reports to the Provincial Petroleum Directorate.

Speculation on the reasons for the continuance of this unsatisfactory state of affairs would be just that--speculative. It is sometimes suggested that the oil companies are anxious to improve their accident statistics and that workers are given various incentives not to report accidents. Whatever motivations may be at work the reporting of accidents and accident rates to the Petroleum Directorate of Newfoundland and Labrador is in an unsatisfactory state.

Another source of information is in the reporting of accidents to the Worker's Compensation Board of Newfoundland and Labrador prior to 1976 and under present legislation to the Provincial Department of Labour with which responsibility for Occupational Health and Safety now rests.

The Provincial Department of Labour has introduced a standard reporting system to be followed by all companies and drilling contractors. The forms have been sent many times to the Department in an incomplete state. The Department now reports that incomplete forms are being returned to the companies for completion. A computer data management system is being introduced. At present the data are being compiled by hand and the Department was able to supply data for the year 1983 only.

The monthly tabulations available for the Newfoundland and Labrador Department of Labour use the following table headings:

--number of lost-time accidents;

--number of non lost-time accidents;

--total number of accidents;

--person/hours worked;

--lost-time accident frequency;

--accident frequency for all accidents;

--company reported lost-time accident frequency;

--industry-wide rate of lost-time accidents.

The major deficiency in the data available from the Department of Labour (Newfoundland and Labrador) is that person/hours worked are not consistently reported, and so frequency rates cannot be calculated by the Department or as part of this study.

Neither the Petroleum Directorate nor the Department of Labour know the actual number of people working on the offshore drilling rigs.

It should be acknowledged that such a counting exercise is not as simple as it may appear. People are continually being moved on and off the MODU's. In addition to workers going and returning from leave, the work force includes sub-contracted labour hired for repair jobs and a variety of service personnel under contract to different companies, many of whom are only on the MODU's for short periods of time.

In addition to the Petroleum Directorate and the Department of Labour statistics are also kept by the Newfoundland and Labrador Worker's Compensation Board under the following headings:

--nature of injury

--part of body affected

--source of injury (if recorded)

--type of claim

--medical aid cost

--lost time cost

--time of disability

--amount of permanent/partial disability award

--amount of fatal award

--accident frequency of employer (number of accidents)

--type of industry.

The data are compiled from employer accident reports for claim payments. The Worker's Compensation Board data therefore includes the most reliable and comprehensive set of information on accidents that are considered severe enough to warrant a claim for compensation. The Board's

prime responsibility is to make benefits available to injured workers and to process claims with reasonable speed. Claims are therefore processed without all the above information. While the Compensation Board accident data are probably the most complete and reliable, the accident frequency rate is again unreliable due to the lack of proper "hours of exposure" data.

A further complication with Worker's Compensation Board data is that it is tabulated by categories of workers. In Newfoundland and Labrador 55 companies were registered in the offshore worker class (Class 1.5) in 1983. However, some workers on the offshore rigs are not placed in the offshore worker category. For example caterers are not included in Class 1.5 in the Compensation Board statistics. In a total loss accident all hands on board a rig are at approximately the same risk level. For this reason the number of offshore workers may be underestimated by the Worker's Compensation Board, with consequent effects upon the reported accident rate. It is also known that some people working for companies registered in the offshore worker category are land-based office workers who are rarely if ever on board the rigs.

Much the same picture <u>mutatis mutandis</u> holds for Nova Scotia as for Newfoundland and Labrador. The Nova Scotia Worker's Compensation Board data, for example, have an occupational category entitled, "oil and drilling". This category includes workers both onshore and offshore as well as geophysical prospecting.

Companies active in the offshore oil and gas industry also report to the Canada Oil and Gas Lands Administration (COGLA) at the federal level of

government. Examination of the data on file in Ottawa also reveals them to be incomplete and stored in a "raw" form. The accident reports are filed but the data are not being abstracted and tabulated.

If reliable objective knowledge of the risks to workers involved in the offshore oil and gas industry is considered important enough then a first step must be the establishment of a proper comprehensive and reliable fatality and injury reporting procedure, together with ongoing or periodic analysis of the data.

From the perspective of the workers, the important thing is rapid and sufficient compensation for injuries. Data reported for this purpose do not meet the criteria of completeness, reliability and objectivity.

From the perspective of the regulatory bodies at Federal and Provincial levels, the important thing is to monitor the safety performance or accident record of the industry. Data reported for this purpose do not meet the criteria of completeness, reliability and objectivity.

From the perspective of the companies in the industry, there is no doubt too much reporting and form filling to be done to a multitude of agencies. It has even been suggested that the amount of regulation and action to comply with regulation diverts attention away from some of the more obvious safety precautions that could be taken.

For the purposes of assessing risk the data available on the Canadian eastern offshore oil and gas industry are totally unsatisfactory. It is beyond the terms of reference of this study to suggest how such a situation might be remedied. It is appropriate to call attention to the problem and to urge speedy resolution of it.

International data

Similar problems are reported from other countries, so that data reported from the United States, the United Kingdom and Norway in subsequent sections of this report are subject to similar limitations, not all of which are so serious as in the Canadian case.

A number of papers and reports have been prepared to show the overall level of risk in the world-wide offshore oil and gas industry. These refer mainly to loss of MODU's and loss of lives. It might be expected that the ambiguities and confusions which arise in the reporting of accidents would be avoided when it comes to rigs and lives. Either a rig is lost or not lost. Either a worker is dead or alive.

Unfortunately even here discrepancies arise. The original source of most of the data reported appears to be "Lloyd's Weekly Casualty Reports" which contains information on all marine accidents, but which is probably selective in terms of the Lloyd's insurance interests. A number of authors appear to use the Lloyd's Weekly Casualty Reports and supplement them with their own data and in any case their own interpretations.

International data are also available from the Offshore Rig Data Service of Houston, Texas and from a new service established by Det norske Veritas entitled World Wide Offshore Accidents Databank.

Despite these services, wide variations appear in the numbers of accidents reported, the total loss of MODU's and number of fatalities. Total numbers of accidents involving mobile drilling rigs are shown in Table 1.

TABLE 1

NUMBER OF MISHAPS REPORTED INVOLVING MOBILE DRILLING RIGS. WORLD-WIDE DATA

Number of Accidents	Time Period	Source
140	1955-March 1981	LeBlanc (Offshore, March 1981)
207	same period	Offshore Rig Data Service (1983)
171	1955-1982	Ocean Industry (1982)
245	same period	Offshore Rig Data Service (1983)
107	1972-74	Snider et al. (Marine Technology, 1977)
95	1955-74	Thorbe (Offshore, June 1974) cited by Snider.

Offshore Rig Data Service reports a substantially higher number of accidents than the industry magazine, _Offshore_ (LeBlanc, 1981) for the same period of time (1955-March 1981). Similarly in Table 2, it is shown that in the period 1976-80 some 20 MODU's were totally lost according to Offshore Rig Data Service whereas _Offshore_ gives only 14 (LeBlanc, 1981).

Different numbers of fatalities are also cited. For example, _Offshore_, (April, 1982) reports 326 fatalities from 5 accidents in the period 1976-82. The _Offshore Accident Review_ (August, 1983) reports 349 lives lost in only 4 accidents from 1979-82.

In the analysis which follows judgements have been made about which estimates or data sources are most reliable. In general the higher figure has been used on the grounds that accidents and fatalities might go unreported, but accidents and fatalities that have not occurred are unlikely to be invented. It is also thought more prudent to overestimate risk than underestimate it. In a growing industry, where largely new technology is being used in hostile environments, prudence requires that errors be made on the side of safety. The purpose is not to exaggerate the risk, but to be especially careful to avoid underestimating it.

3. _Little Risk Modelling_

In Part One of this report the use of risk modelling by event- and fault-tree has been described as a means of "letting theory be your guide". The development and application of such methods including system safety analysis goes well beyond the scope of this report.

TABLE 2

TOTAL LOSS OF RIGS IN THE WORLDWIDE MODU FLEET

	1956-60	1961-65	1966-70	1971-75	1976-80	Total
Offshore Rig Data Service (1983)	7	10	10	16	20	63
LeBlanc (<u>Offshore</u>, March 1981)	5	8	10	9	14	46
<u>Ocean Industry</u> (Oct. 1980)						45
Snider (<u>Marine Technology</u>, Oct. 1977)				(1972-75) 20		
Thorbe (<u>Offshore</u>, June, 1974)						(to 1974) 36

Any commentary on the risks of offshore oil explorations in Canada must nevertheless address the question of the necessity for or desirability of such analysis. A modelling approach to risk analysis would have two main advantages. It would provide an alternative way of measuring the probability of large scale disastrous accidents. Given the unreliability of other data and the shortness of the period of research this might be helpful. Second, a modelling approach would help to identify possible causes of accidents and accident sequences that might lead to accidental deaths and injuries. Identification of such possibilities is the first step towards corrective action.

On the other hand, risk modelling is costly and time consuming and would probably require more resources than are available to the Royal Commission on the Ocean Ranger Marine Disaster. Furthermore the apparently greater precision in risk estimates that might be achieved may be knowledge that is not needed or is not worth the cost of obtaining it. Possible causes of accidents might be identified in other ways by designers of MODU's and drilling platform safety inspectors.

The most logical approach at the present time seems to be to rely on historical and transfer of experience types of analysis, and to learn what lessons are available from risk modelling elsewhere. Managers in the Canadian offshore industry should be fully acquainted with the Norwegian work in order to make use of it in their own policy, management, operational and design decisions. The most complete report currently available in English is by Jensen, Vedeler and Wulff (1979).

II

STRUCTURE OF THE REPORT

Offshore oil and gas explorations are relatively new in Canada and still on a small scale compared with the rest of the world. The report therefore considers the world-wide perspective first and then experience in other countries where drilling has a longer history before turning to the Canadian scene. This approach permits the Canadian data to be readily seen in the context of the offshore oil industry as a whole.

An essential preliminary to the examination of historical accident data is the knowledge of how accidents may be caused in ways peculiar to the offshore industry. The next section therefore deal with the hazard events themselves.

III

THE HAZARD EVENTS

The literature on offshore oil explorations contains at least two papers which discuss the causes of accidents. Knowledge of causes is an obviously important step in risk analysis. If certain causes occur more frequently than others they represent the priority point of attack for any risk management or risk reduction strategy.

Counting frequencies requires a prior classification scheme, and the value of any frequency count depends in part upon the classes created and how they are defined.

What are the sorts of events that can occur in offshore oil and gas exploratory drilling that might cause injury or fatality? Risk analysis teaches us that injuries or fatalities can rarely be attributed to a single event or cause. A hazard event on close examination always proves to be a sequence of events.

In offshore oil explorations the cause of an accident can include the weather and other environmental conditions; the design and operation of the MODU itself; and the capability of those on board and emergency service personnel to deal rapidly and effectively with a dangerous situation. Examination of reports of accidents at sea reveals that almost always all three sets of factors are involved.

It is always a simplification to speak of a single cause or of a cause as a single event. In theory, the logical approach to the analysis of

hazard events is to identify "event sequences". Risks can then be calculated in terms of the probability of whole event sequences rather than separate events. A complete risk analysis of offshore exploratory drilling would require the development of a comprehensive set of event sequences and their classification into like sets.

Such an ideal-theoretical approach would permit estimates to be made of risks of accidents on quite a different basis, and would also help to identify "weak spots" where added increments of safety precautions are needed.

In the absence of such analysis the task of risk assessment is forced to rely upon more primitive concepts of cause in order to relate them to the historical accident record. The most widely quoted classification of causes is by LeBlanc (1981) and is shown in Table 3 and is used in Figure 1 to show the frequency of mishaps by causes. A similar classification from Offshore Accident Review (1981) is also listed in Table 3.

There are severe weaknesses in such classification from a statistical point of view. The categories are not mutually exclusive. For example a loss of a rig while being moved in a storm could be classified as caused by "towing--rough weather" or "storm". Presumably in this case the category "towing" means that the "storm" categories refers only to stationary rigs. But it is not clear. There is, however, no double counting. All 140 mishaps have been allocated to one category only.

The classification does not list all possible causes of mishaps. For example, rigs might be struck by an iceberg, affected by an earthquake

TABLE 3

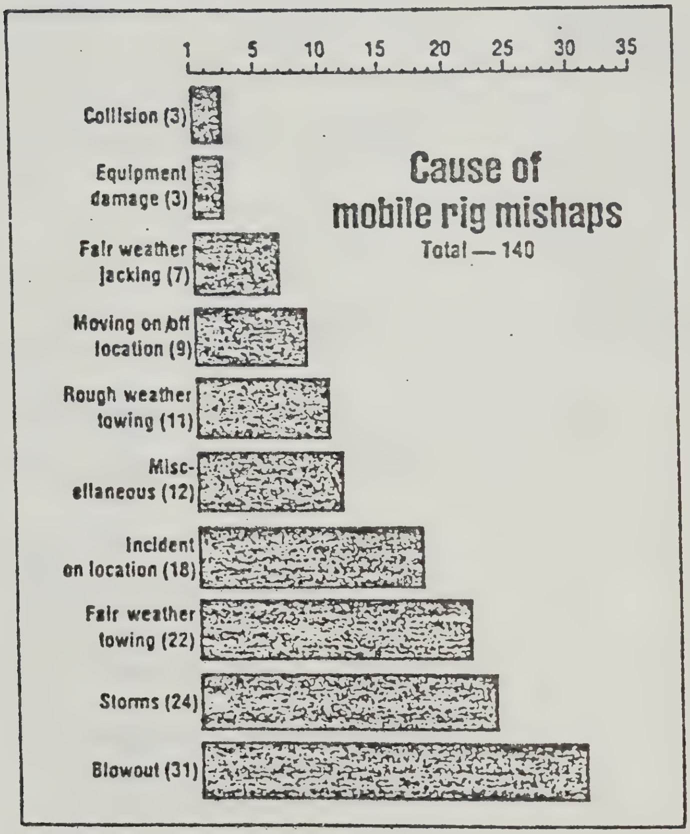
CLASSIFICATION SYSTEMS FOR OFFSHORE ACCIDENTS

LeBlanc, *Offshore*, 1981	*Offshore Accident Review*, 1983
Blowout	Blowout
Storm	Weather
Towing-fair weather Towing-rough weather	
Incident on location	
Moving on/off location	
Fair weather jacking	
Equipment damage	Machinery
Collision	Collision
Miscellaneous	Other
	Capsizing
	Grounding
	Leakage
	Fire
	Explosion
	Out of position
	Foundering
	Structural damage

FIGURE 1

CAUSES OF MOBILE RIG MISHAPS 1955-1981

(WORLD WIDE DATA FOR 140 MISHAPS)



Source: LeBlanc, L., "Tracing the Causes of Rig Mishaps", Offshore, March, 1981, pp.51-62.

and/or tsunami, or hit by another vehicle such as a supply ship or a helicopter. Acts of war, sabotage or vandalism cannot be ruled out. Accidents may occur not only on the rig itself but in associated activities such as diving.

The LeBlanc classification shows that, of the 140 mishaps classified in the period 1955-81, 31 are due to blowout and 24 to storms. The LeBlanc data also show (Figure 2) that most mishaps happened to jackups.

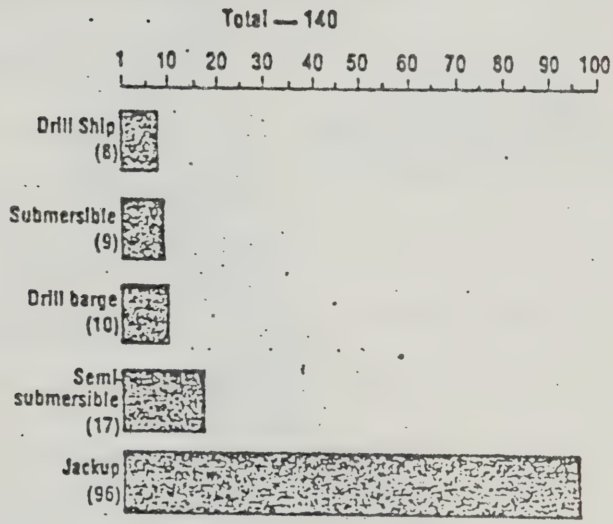
The difficulty with such classifications from a risk point of view is clear. They do not really address the issue of cause in an accurate way. In Section I, Objectives and Limitations, certain data deficiences were described for Canada. When it comes to making cross-national comparisons these difficulties are compounded by lack of standard reporting categories. If data are to be more systematically collected in Canada and elsewhere in the world a standard international classification scheme is required so that data will be consistent over time in each place and be more comparable from country to country. Under present circumstances, data are incomplete and unreliable for each country and are not strictly comparable internationally.

The precise design of any standard system of classification requires careful consideration of the purposes for which the data are to be collected. As noted above, data reported to regulatory bodies or compensation boards is not strictly appropriate for the purposes of risk analysis.

The International Labour Organization has an ongoing interest in such matters and has published reports on worker safety in the offshore industry (1978). It might therefore be an appropriate body to take up the issue of statistical reporting on offshore accidents.

FIGURE 2

TYPES OF MOBILE RIG DAMAGED OR LOST



Source: LeBlanc, Offshore, March 1981, p.61.

IV

A WORLD WIDE PERSPECTIVE ON RISK OF FATALITY

World wide data assembled by Offshore Data Services (1983) are the most comprehensive. Sixty three drilling units have been totally lost in the period 1956-1980. Over this 25 year period there have been 5,125 rig years of drilling activity, giving an observed lost rate overall of 1.2% (Table 4).

Taking the Offshore Data Services (ODS) data at face value, we observe that the average expectation of a total loss accident is one rig lost per 81.3 rig years. This gives a rather crude estimate of risk which is subject to three main qualifications. First, the record has improved over time. In the 10-year period between 1955 and 1965 the ratio of total loss accidents to rig years was 2.1%; in the 1976-80 period, however, the ratio dropped to 0.9%. The downward trend may be expected to continue as experience accumulates and as the technology and design of MODU's improves (Starr, 1972).

It is a common experience that risks are higher in the early period of the introduction of a new technology. While offshore drilling is not completely new, (it began in a small way more than 80 years ago) the greater depth of water where drilling operations are now taking place has only been made possible by the introduction of substantially new drilling technology. The world-wide fleet of MODU's was very small prior to 1960. The technology is substantially new since 1960 and has been improving.

TABLE 4

TOTAL LOSS ACCIDENTS PER RIG YEARS

Rig Years / Accidents

	1956-60	61-65	66-70	71-75	76-80	Totals	Percent Ratio
Submersibles	128/1	143/0	139/0	101/1	98/0	609/2	.33%
Jackups	118/5	208/6	445/8	639/12	1041/16	2451/47	1.9%
Barges	57/1	87/2	124/1	137/2	142/0	547/6	1.19%
Drillships	16/0	42/0	95/0	144/0	268/0	565/0	0.*
Semi-Submersibles	8/0	18/2	99/1	250/1	578/4	953/8	.84%
Totals	327/7	498/10	902/10	1271/16	2127/20	5125/63	
Percent Ratio Per Total Rig Year Period	2.2%	2.0%	1.1%	1.3%	0.9%	1.2%	
Cumulative Percent Ratio		2.1%	1.6%	1.4%	1.2%		

* The drillship Glomar Java Sea was lost in the China Sea in 1983.

Source: Offshore Rig Data Services, Research and Consulting Division, 1983. Accidents: Offshore Mobile Drilling Rigs 1955 to Present. Houston, Texas.

Second, the risk of total loss accidents varies according to the type of MODU. Thus the composition of the MODU fleet in any one region affects the expectation of loss. As shown in Table 4, the ODS data indicate that the loss rate is highest for jackups (1.9%) and lowest for drillships.

Of the 33 MODU's that have operated in the eastern Canada region between 1970-1983 there were 15 semi-submersibles, 12 drillships, and 6 jackups. Jackups are in limited use in Nova Scotia waters only. These are the MODU's with the highest total loss accident rate (1.9% world wide). Drillships have the best record (up to 1980 no total loss accidents are reported in 565 drillship years of world-wide operation)* and these are the second most frequent type of MODU in use. The total loss accident rate for semi-submersibles is 0.84% and this type accounts for 15 of the total fleet of 33 MODU's in Canadian waters. The composition of the Canadian eastern offshore fleet, especially the small number of jackups, suggests that the world-wide data may overestimate the risk. (See Table 21).

Third, the risk might be different in the various regions of the world where offshore drilling takes place. In the earlier period a greater proportion of the drilling took place in shallow waters and in less harsh environments. With the extension of drilling into the North Sea and the Canadian east coast, those dangers associated with very rough weather and cold water, have become greater. In addition, the problem of icebergs in the Canadian offshore is one that has not previously been encountered.

*The drillship Glomar Java Sea was lost in the China Sea in 1983.

As shown in Table 5, foul weather during the movement of a MODU or a storm on location are given as the "cause" of 38 out of the 63 total loss accidents reported. Insofar as foul weather and storms constitute a greater risk on the Canadian eastern offshore, then the world wide data may underestimate the risk.

Thus it seems that when Canadian eastern offshore risks are compared with world-wide rates, two factors suggest that risks in Canada should be lower (the time or learning factor and the composition of the fleet--less jackups) and one factor (the harsh environment) suggests the possibility of higher risks than world-wide averages.

Assuming an expectation of one total rig loss accident per 81.3 rig years, and the level of offshore activity in the study area of 6.1 rigs (1982), then we can say that the expectation of a total loss rig accident in 1982 was .075. In this context the loss of the Ocean Ranger on 15 February 1982 was not so improbable. The probability of losing one MODU was seven chances in a hundred.

There is of course no necessary relationship between the risk of a total loss accident to a MODU and the risk to the workforce aboard. It depends upon the chances of being taken off the rig before it sinks or of being rescued from lifeboats on the sea. The possibilities of such rescue are probably lower in the harsh environment of the eastern Canada offshore than in most other parts of the world where such activity is taking place.

Four major accidents have been reported including one each in 1979, 1980 and 1982. These are listed in Table 6.

TABLE 5

CAUSES OF TOTAL LOSS ACCIDENTS

(WORLD-WIDE) 1955-1980

	ENROUTE FOUL WEATHER	STORM ON LOCATION	BLOWOUT	OTHER	TOTAL COST
Jackups	20	7	10	10	$415.4 MM
Barges	1	3	2	0	13.9
Semisubmersibles	2	3	2	1	140.1
Submersibles	0	2	0	0	5.1
Drillships	0	0	0	0	0 *
TOTALS	23	15	14	11	$574.5 MM

*The drillship Glomar Java Sea was lost in the China Sea in 1983.

Source: Offshore Rig Data Services, Research and Consulting Division, Accidents: Offshore Mobile Drilling Rigs 1955 to Present, Houston, Texas, 1983.

TABLE 6

MAJOR LOSS OF LIFE ACCIDENTS ON MODU'S

Year	MODU	Location	Fatalities	Survivors
1979	Bohai II	South China Sea	70	?
1980	Alexander Kielland	North Sea (Norway)	123	89
1982	Ocean Ranger	Eastern Canada	84	0
?	Bohai III	?	70	?
Total			349	

A person accepting a job on an eastern Canada offshore rig might reasonably ask, "What risk am I taking?". One response to this question is to make the highest possible estimate by interpreting the data in their worst light. There has been only one serious disaster in the eastern Canada offshore area and in that event all 84 persons on board the Ocean Ranger were lost. Thus if the probability of the total loss of a rig is one per 81.3 rig years (from Worldwide data, Table 4) and if all persons on board were lost then the chance of being killed for a person who spends a whole years on a rig is not greater than .012. If a person is only on the rig half the time then the risk of being killed is not greater than .006 or 6 chances in 1,000 or 1 in 166. It should be emphasized that this is a worst case scenario, and that the risks could well be considerably less and are not likely to be any greater.

Individual risk data for Canada have not been calculated but a comparison with U.S. data is instructive, allowing for some differences between the U.S. and Canada. As shown in Table 7 the probability of a person in the U.S. being killed in an accident of any kind is 1 in 2,000--this includes all population and not simply those exposed to occupational risks. It is obvious that those engaged in dangerous occupations have a higher degree of risk than the total population. But compared with the individual risk levels in Table 7 the eastern Canada individual risk of death of 1 in 166 seems high even for a worst case estimate.

TABLE 7

INDIVIDUAL RISK FROM VARIOUS ACCIDENTS AND NATURAL DISASTERS (U.S.)

Accident Type	Total Fatalities	Individual Risk per Year
All Accidents	115,821	1 in 2,000
Motor Vehicls Accidents	55,511	1 in 4,000
All Industrial Accidents	14,100	1 in 6,000
Falls	16,506	1 in 13,000
Drowning	7,152	1 in 29,000
Fires	6,503	1 in 32,000
Poisoning	5,335	1 in 40,000
Airplane Crashes	1,668	1 in 130,000
Railway Accidents(all railway accidents)	789	1 in 250,000
Lightning	160	1 in 1,300,000
Tornadoes	90	1 in 2,300,000
Dam Failures	35	1 in 5,700,000
Gasoline Tank Truck Accidents	28	1 in 7,400,000
Propane Transportation Accidents	15	1 in 15,000,000
Chlorine Rail Car Accidents	9.4	1 in 22,300,000
Air Crashes (persons on ground)	6	1 in 33,000,000

Source: Andrews, W.B. Pacific Northwest Laboratory 1980.
Various dates for fatality estimates 1980 - 85.

This fatality risk level of 1 in 166 is the risk of simply being on the rig (MODU) for 50% of the time over a year. It does not include industrial accident risk, i.e. the risk of being killed as a result of an accident while working. Nor does it include the risk while being transported from land to MODU and back by helicopter or vessel. Nor does it include the risks a person faces for the other 50% of the time on land.

This analysis of world wide data suggests that simply being on an offshore rig is very dangerous when compared with the risks of everyday life. It might then be asked, "How common or how rare an event is something like the loss of the Ocean Ranger with all hands?".

The level of activity in the study area over the period 1970-83 has been a total of 50.8 rig years of operation (24.5 rig years in Nova Scotia waters and 26.3 rig years in Newfoundland and Labrador waters). If the expectation of a total loss accident (from world-wide data) is one loss per 81.3 rig years then the expectation of a loss in the Eastern Canada offshore region during the period is .62 or 62%. The fact that there has been one total rig loss (the Ocean Ranger) is well within range of variance of such an estimate.

The main concern of this study is risk to people rather than risk to MODU's. Data sources presently available permit only very qualified and approximate estimates of the risk to persons. This is chiefly because accident statistics are incomplete and subject to biases in reporting, and reliable data on exposure - or person years of time spent on MODU's are not available.

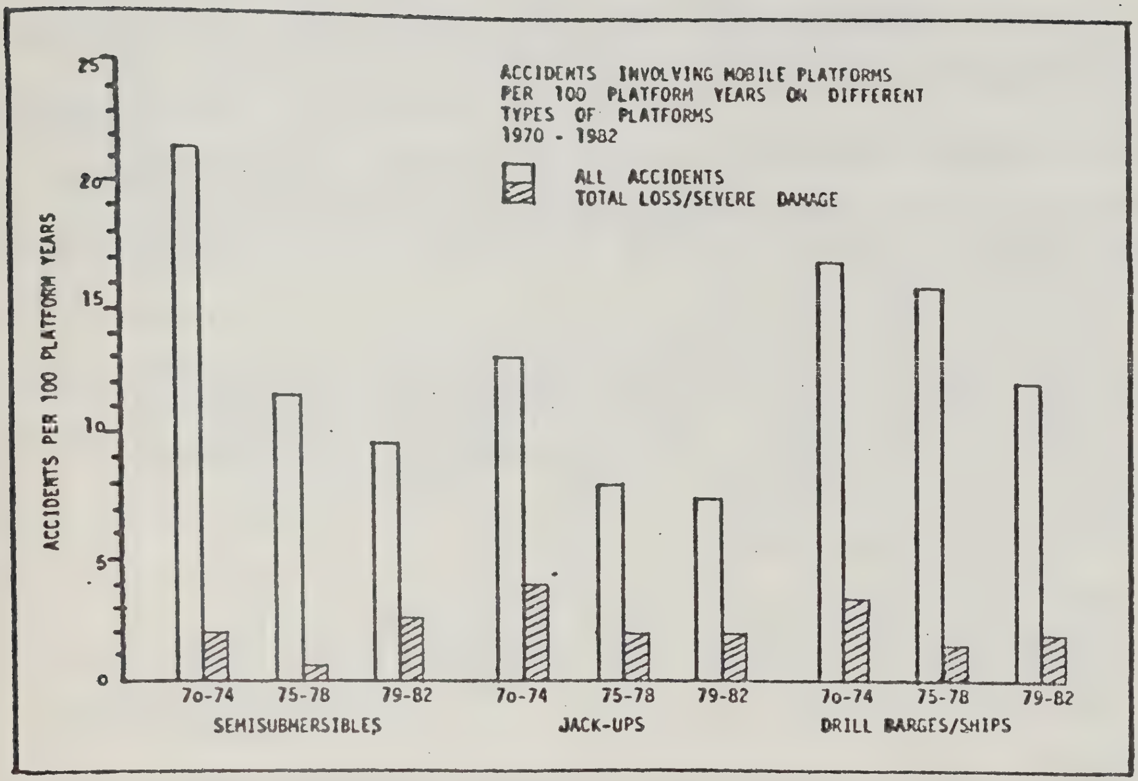
Recently, however, the organization Det norske Veritas has established a Worldwide Offshore Accident Data Bank. As shown in Figure 3 the level of fatalities per 1000 persons has shown a decline over the period 1970-78. This decline is interrupted by the sequence of 3 major accidents in the 1979-82 period resulting in the loss of 277 lives. There is no explanation for the "cluster" of 3 major accidents in 4 years. It is most probably a random phenomenon.

It seems reasonable to divide offshore drilling fatalities and injuries into two distinct populations. These might be described as marine disasters and industrial accidents. The evidence which follows tends to show that the rate of "routine" types of industrial accidents is lower in offshore drilling than in similar onshore activities and lower than in other offshore activities.

On the other hand there is a possibility of disaster which can result in the loss of all hands. From a risk analysis perspective, it is desirable to address the two risks separately, because different approaches to risk reduction are needed in each case. In the case of industrial accidents it may be that the safety precautions applied on land, with some necessary changes, are sufficient. In the case of marine disaster, the focus has to be on making the offshore drilling rigs less vulnerable to accidents that may result in their total loss, and on making emergency plans and precautions to maximize the possibility of rescue when a disaster does occur.

FIGURE 3

Trends in MODU Accidents



Source: Det norske Veritas (Canada)Ltd. 1984 Critical Systems Study Vol.1.,p.27

V

RISK ON THE U.S. OUTER CONTINENTAL SHELF

Data for the United States have been obtained from a U.S. National Research Council study entitled Safety and Offshore Oil (1981). This is the most comprehensive study of the safety of offshore oil exploration and production activities so far conducted in North America. Nevertheless it is restricted in various ways.

> "The committee excluded detailed consideration of the health of offshore workers, air pollution, diving, and transportation of people and materials to and from offshore structures....". "Nor did it attempt to assess the vulnerability of offshore structures to sabotage or attack". (p.xviii).

The study is also limited in other ways.

> "No comprehensive source of data on accidents in outer continental shelf (OCS) operations exists. The committee collected and analyzed data from a number of sources and made estimates as needed, e.g. the size of the OCS work force."

It goes on to warn, however, about the quality of the data in the following terms:

> "Both the Geological Survey and the Coast Guard require the reporting of lost-time injuries and fatalities that occur in OCS operations. Industry keeps workplace safety statistics and makes a summary of its data available to the public. These data are collected for different purposes, and the methods of collection and format of presentation vary. This results in workplace safety data that are neither consistent nor comparable between data banks. Also, the data are not necessarily comparable to that of other industries such as mining and shipyard construction, with which safety comparisons could be useful."(p.15)

For these reasons the National Research Council study goes on to recommend that:

> "The Coast Guard and the Geological Survey should coordinate and strengthen the collection of workplace data. A single accident-reporting form collected by a single agency could provide the kind of information needed to gain better understanding of the causal factors and characteristics of workers that could lead to improved safety."

Similar action should be considered in Canada for reasons that have been discussed.

1. <u>The Outer Continental Shelf (OCS) Workforce</u>

It is reported that at the end of 1979 about 61,500 U.S. workers were regularly employed in OCS oil and gas exploration, development and production. The estimate is qualified as "very tentative" since no census of the OCS workforce has ever been undertaken. Over the ten-year period 1970-79 the OCS workforce grew by approximately 34,000 full-time equivalents (one F.T.E. is 2,000 man-hours per year) (p.134). This represents an elapsed growth of 71 percent over ten years.

2. <u>The Safety Record</u>

In the nine-year period 1970-78 the U.S. Geological Survey reported that 187 workers were killed in 116 accidents on the OCS. A partial data set of fatalities and fatality rates is given in Table 8. The data suggest that both the number of fatalities and the rate of occurrence are declining.

Although statistics on injuries are not thought to be highly reliable, the available evidence reported by the N.R.C. study shows that injuries are declining at least in drilling operations.

> "Although the total number of drilling man-hours reported for the OCS increased from 26 million to 105 million between 1962 and 1977, the accident frequency for the same period declined

OUTER CONTINENTAL SHELF FATALITIES (1) (U.S.)

	1976	1977	1978	1979	Total
U.S. OCS Fatalities	49	42	44	39(2)	174
Rate (per 100,000 workers per year)	112.7	95.8	85.4	61.6	

(1) This Table takes into account total exposure of workers to risk, both on and off duty.
(2) Data for 1979 may be low because of reporting delays.

Source: U.S. Coast Guard, based on data from the Coast Guard, Geological Survey and Office of Workmen's Compensation. Reported in Safety and Offshore Oil, p.135

from 14.9 to 9.3 accidents per 100 man-years". (p.134) "In other words there was a fourfold increase in exposure-hours but a 35 percent decrease in accident frequency."

3. Comparison with Other Industries

The NRC study reports as follows:

"The frequency of injuries on oil and gas operations on the OCS is comparable to that of other industries, such as mining, maritime transportation, and heavy construction, and also offshore operations in other countries. For example, the injury rate in the deep-sea maritime transportation industry in 1979 was 38.4 percent, while the incidence of personal injuries in OCS operations was 23.4 percent. The injury and illness rates per 100 full-time workers in all oil and gas extraction activities totalled 13.9 in 1978, about the same as general manufacturing (13.2)." (p.136)

Comparisons of this sort must be qualified by knowledge that definitions of "injury", interpretations of definitions, and reporting practices vary widely from industry to industry and company to company.

4. Gulf of Mexico versus North Sea

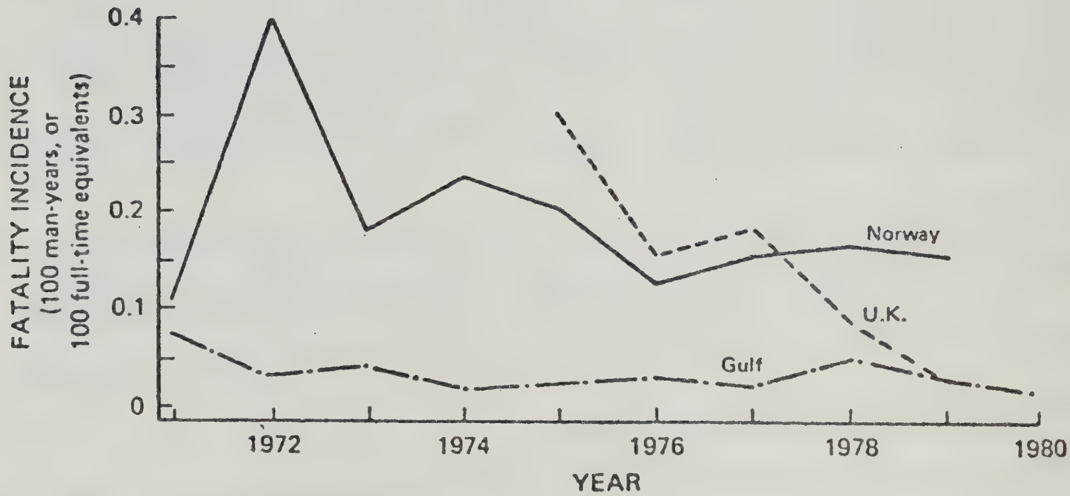
The NRC study compares fatality rates between the Gulf of Mexico OCS and the North Sea. As shown in Figure 4, the incidence of fatalities is lower in the Gulf of Mexico, where the rate is holding relatively constant. The data available to the National Research Council study was sufficient to convince them that "the incidence of fatalities is declining in the North Sea". (p.136)

5. Fatalities and Injuries by Activity, Type of Accident and Cause

The incidence of Gulf of Mexico OCS accidents involving fatalities is shown in Table 9 by the type of operations, by type of accident and cause.

FIGURE 4

COMPARISON OF FATALITIES IN THE GULF OF MEXICO AND IN THE NORTH SEA



Reported in Safety and Offshore Oil, ,p.137.

TABLE 9

GULF OF MEXICO ACCIDENTS INVOLVING FATALITIES 1970-1979

By Operation	Events	Percent	Fatalities	Percent
Drilling	55	47	79	42
Completion	15	13	25	13
Construction	2	2	2	2
Production	42	36	77	41
Abandonment	2	2	4	2
By Type of Accident				
Fire/Explosion	14	12	36	19
Machine or Equipment Failure	39	34	51	27
Personal	44	38	44	24
Vessel Mishap	5	4	14	7
Helicopter Crash	4	3	31	17
Blowout	1	1	1	1
Wave	3	3	4	2
Unknown	6	5	6	3
By Primary Cause				
Mechanical	50	43	76	41
Human	47	41	81	43
Natural Event	4	3	5	3
Unknown	15	13	25	13
TOTAL	116		187	

Source: Adapted from data in the U.S. Geological Survey Events File; reported in Safety and Offshore Oil, p.138.

Both drilling and production account for a high proportion of fatalities, and the most numerous types of accidents involving fatalities are fires/explosions, machine or equipment failure and personal accidents. Blowouts, commonly described as "the most feared of gas drilling risks" are linked to surprisingly few fatalities, unless the category "fires and explosions" includes some events caused by blowouts.

The issue of "cause" or "primary cause" presents difficulties of definition and classification. The NRC study reports that,

> "the causal data in the table are not adequate to support exhaustive analysis but the Committee's review of the Geological Survey's Events file indicates that most mechanical failures can be traced to an error in operations or maintenance." (p.136)

The NRC study used workmen's compensation lost-time injury reports to compare injury data among types of outer continental shelf activities. As shown in Table 10, most injuries occur in the "service" category, which is a group including such varied and common services as material handling and housekeeping. It is surprising that the activities least directly involved with the actual drilling operation should produce such a high proportion of the lost-time injuries. An explanation may well lie in patterns of reporting and the consequences of "lost-time" to different employee categories. Even when allowances for such factors are made, the data do not suggest a high level of risk for workers in the offshore industry in the Gulf of Mexico.

TABLE 10

PERCENTAGE OF INJURIES BY OCS ACTIVITY

(1976-1977)

Activity	Percent of Injuries
Service	31%
Drilling	27%
Well Service	14%
Production	11%
Construction	10%
Workover	5%
Other (geophysical, helos, etc.)	2%

Source: U.S. Coast Guard, OCS Safety Project; based on Workmen's Compensation injury data reported on form LS-202; reported in Safety and Offshore Oil, p.139.

6. Factors in Workplace Accidents

The NRC study also considers the various factors that enter into workplace accidents in the outer continental shelf. It is concluded on the basis of data from the International Association of Drilling Contractors for 1978, that "the drilling accident rate is nearly 15 percent lower for marine oil and gas operations than for those on land" (p.140). On the other hand it is recognized that the landing of personnel and equipment from boats or helicopters has an added element of risk not found in land-based operations.

The study ascribes a substantial part of the responsibility for workplace accidents to human characteristics, limitations and attitudes. Experience is a key factor. It is reported that 76.5 percent of injuries occurred to employees with less than one year on the job, and that 54.8 percent of all injuries occurred within the first six months of employment. These figures sound impressive but the high turn over of the workforce means that a disproportionately large part of the workforce work for short periods. There is some evidence that the rate of injuries declines with length of service with the company as shown in Figure 5.

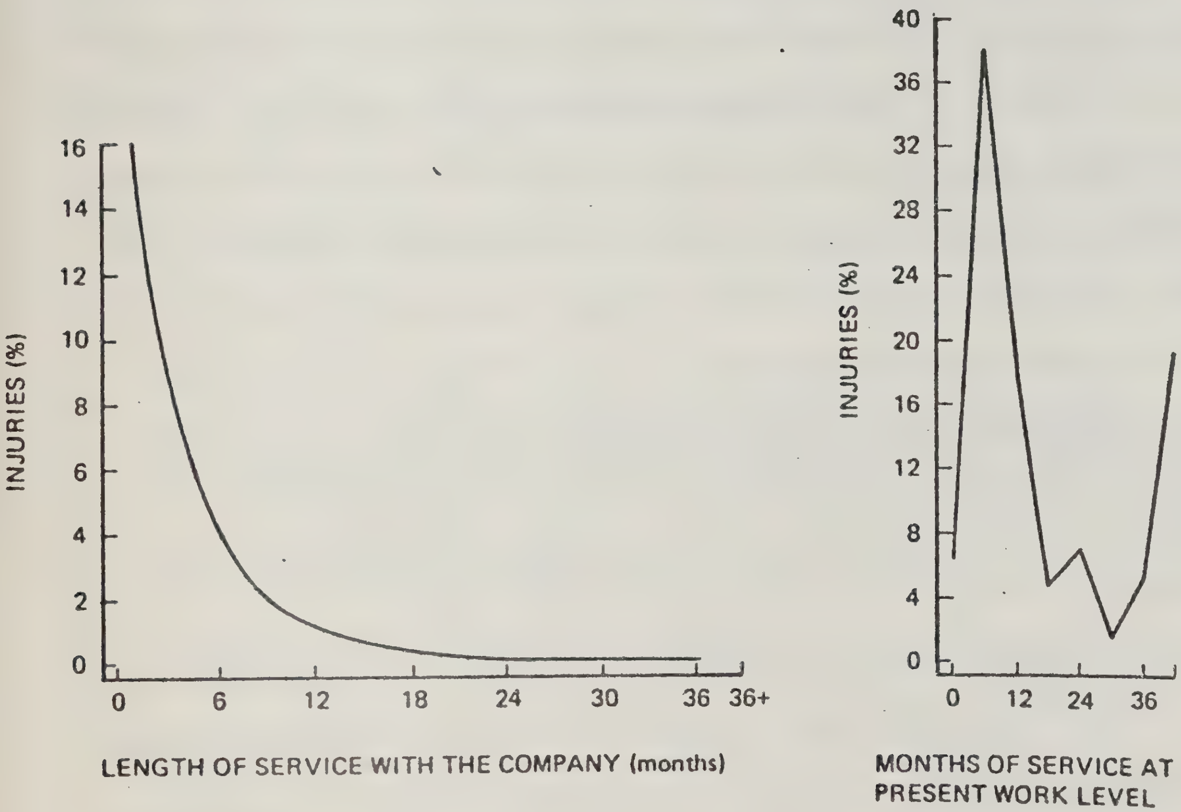
The NRC study finds that,

> "current technology and engineering systems now in use on the OCS appear to provide adequate workplace safety." "Most of the improvement in safety that can be achieved by engineering has already been accomplished." "The principal item demanding attention in improving workplace safety is not technology but improvement in personnel performance." (p.15).

FIGURE 5

RELATIONSHIP BETWEEN INJURIES AND ON THE JOB EXPERIENCE IN OCS DRILLING

(U.S.)



Source: U.S. Coast Guard; reported in Safety and Offshore Oil, p.147.

7. Hostile Environments

It is noted that further expansion of exploration, drilling and production operations in "frontier areas" of the OCS will lead U.S. operators into more hostile environments than those of the Gulf of Mexico and the Pacific. Many companies now operating in U.S. (and, it could be added, Canadian) waters have North Sea experience that can be applied to these new operations. The study "has found no evidence that more hostile physical environments or more difficult operations, by themselves, lead to more accidents." They do however, recognize that more hostile environments "may indicate a need for special measures--protective gear, general procedures, training, supervision and personnel selection" (p.15).

The NRC study concludes that,

> "The knowledge required to ensure workplace safety in extreme environments is already in hand in the cumulative experience of the oil industry and the military services. There is no evidence that additional regulations regarding workplace safety are needed for frontier areas nor that major developments in workplace safety technology are indicated." (p.15).

There is little quantitative evidence that can be used to either support or refute such judgements. They do represent the considered views of informed and qualified experts. Insofar as the eastern Canada offshore oil and gas industry shares equipment, techniques of exploration, management practices and other characteristics with the adjacent areas of the U.S. continental shelf, then the judgements made are applicable to Canada also.

VI

RISK IN THE NORTH SEA - UNITED KINGDOM SECTOR

A major review of the safety of the British North Sea oil and gas developments has been conducted by a Committee established by the U.K. Department of Energy. The report is entitled Offshore Safety and is commonly referred to as the Burgoyne Report after its Chairman, Dr. J.H. Burgoyne (Committee on Offshore Safety, 1980).

As in all other credible reports on this subject the Burgoyne Report contains the inevitable lament about the availability and quality of data. Available U.K. data,

> "exclude diving accidents from vessels outside the 500 metre zone and any accident on such as pipelay barges and support vessels. So figures for the entire "offshore sector" are not available and this makes comparisons with other sectors difficult" (p.104).

Further caveats are stated as follows:

> "Looking at the offshore figures in total one or two further qualifications are required. First there have been doubts cast on the validity of the figures for minor accidents because of under-reporting. Similarly the figures for dangerous occurrences are thought to be unreliable because of doubt about the definition of a reportable occurrence and the difficulty of educating all concerned to make such reports" (p.104).

From discussions with informants, much the same could be said for Canadian data.

1. The United Kingdom Workforce

A U.K. Department of Energy estimate of the workforce in the North Sea in 1974 puts the total at 4,030 and this grew to be approximately 12,500 by

1978. This compares with approximately 61,500 workers in the U.S. OCS in 1979 and high and low estimates for Norwegian waters in 1978 of 16,700 (high) and 9,600 (low) respectively. The Canadian workforce is substantially lower than the British or Norwegian. In considering the size of the workforce the Burgoyne Report states that "this is a small population and it is difficult to postulate trends from the accident figures quoted in this review because of the wide fluctuations" (p.104). This observation applies to Canadian data with even greater reason.

The problem of short time experience and the relatively low number of persons engaged in the industry means that from a statistical point of view the sample is too small to permit really reliable inferences to be made, even assuming that the data reported could be taken to be complete and reliable.

2. <u>The Safety Record</u>

The number of fatalities and serious accidents for the five year period 1974-78 are shown in Table 11. Of the 54 deaths in U.K. waters 16 have been involved in diving. This figure of 30% compares with 8 out of 82 or 10% for Norway. We have no information to suggest why diving should seem to be a proportionately greater risk in the U.K. than in Norway. On the other hand U.K. sources report only 1 helicopter death (out of 54) or 2% whereas the figure for Norway is 34 out of 82 or 41%. Again we have no information which permits us to speculate about why helicopters seem to involve a proportionately greater risk in Norway than in the U.K. We suspect that "sampling variability" can account for most of such

TABLE 11

FATAL AND SERIOUS ACCIDENTS BY ACTIVITY

	Fatalities						Serious Accidents						
	74	75	76	77	78	Total	74	75	76	77	78	Total	Grand Total
Construction		2	4			6		5	12	4	5	26	32
Drilling	5	2	2	2		11	13	26	21	20	10	90	101
Production						—	1	2	4	2	4	13	13
Maintenance			1	4		5	3	6	4	1	5	19	24
Diving	3	3*	6	2	2	16			2	5	5	12	28
Helicopters			1			1			4			4	5
Boats	3	1	1	1	2	8	2	4	7	5	7	25	33
Cranes	1	2	2	2		7	6	7	3	3	4	23	30
Domestic						—							—
	12	10	17	11	4	54	25	50	57	40	40	212	266

*One further diver died from natural causes while diving from an offshore installation.

Source: Department of Energy Brown Book 1979; reported in Offshore Safety, p.106.

discrepancies. When a statistical population is small, one or two chance events can have a disproportionately large effect on averages.

The rates for fatal and serious accidents are shown in Table 12. Serious accidents are not defined but it can be inferred that they involve lost time injuries.

The fatality rate per 1,000 employed ranges from 0.8 to 2.0. This compares with a rate of .6 to 1.12 per 1,000 "workers per year" in the U.S. Outer Continental Shelf and the range of 1.7 to 2.8 fatalities per 1,000 man years in the Norwegian case. The Norwegian rate thus appears to be slightly higher than the U.S. or the U.K. rates. It is not certain, however, that the estimates are comparable. "Per 1,000 employed" (U.K.) and "per 1,000 workers per year"(U.S.A.) are not necessarily the same as "per 1,000 man years" (Norway). It may be, for example, that the Norwegian estimate includes time at sea or on the rig only and not time spent on shore, whereas the use of persons employed data on an annual basis may include a lot of time when the person was not at risk.

3. Comparison with Other Industries

Comparisons of fatality rates and accident rates as reported to the British Health and Safety Commission (HSC) are listed in Tables 13, 14 and 15. On the basis of these data the Burgoyne Committee concluded that:

> "an offshore worker is about twice as likely to have an accident as a worker in general manufacturing and about half as likely as a miner. However, an accident offshore is much more likely to be fatal as exemplified by diving where there are more fatal than serious accidents. The categories with the worst accident records are diving, drilling, construction, boats and cranes. Re-allocation of crane accidents does not affect this conclusion as virtually all would be construction or drilling accidents" (p.104-105).

TABLE 12

RATES FOR FATAL AND SERIOUS ACCIDENTS (U.K.)

Year	Estimated numbers employed on installations	Number of fatal accidents (approximate rate per 1000 in brackets)		Number of serious accidents (approximate rate per 1000 in brackets)	
		Installations	Vessels	Installations	Vessels
1974	4030	9 (2·0)	3	19 (4·5)	6
1975	6300	9 (1·5)	1	46 (7·5)	4
1976	9200	16 (1·5)	1	50 (5·5)	7
1977	12100	10 (0.8)	1	35 (2·9)	5
1978	12500	0	4	33 (2·6)	7

Source: Department of Energy Brown Book 1979; reported in Offshore Safety, p.106.

TABLE 13

Incidence rates per 100 000 at risk of fatal accidents reported to HSC enforcement and other authorities, 1972–76

Sector	1972	1973	1974	1975	1976
HSC enforcement authorities					
1. Factories Act:					
Manufacturing industry	3·9	4·2	4·5	3·7	3·4
Construction industry	18·7	21·6	16·0	17·7	15·3
2. Regulation of Railways and Railway Employment (Prevention of Accidents) Acts*	19·7	18·3	14·8	18·7	18·8
3. Mines and Quarries Act:					
Coal mines	22·1	29·6	18·7	24·7	19·6
Quarries‡	40·7	29·0	31·2	29·6	32·6
4. Agriculture (Safety, Health and Welfare Provisions) Act	—	14·7	10·9	11·7	14·1
Other authorities					
5. Merchant Shipping (Returns of Births and Deaths) Regulations					
Merchant Seamen§	136	91	91	120	92

*Accidents to staff engaged in the operation of British Railways, London Transport and Freightliners Ltd only are included in the rates.

‡Including opencast coal sites.

Source: <u>Offshore Safety</u>, p.108.

TABLE 14

Incidence rates per 100 000 at risk of total accidents* reported to various HSC enforcement and other authorities, 1972–76

Sector	1972	1973	1974	1975	1976
HSC enforcement authorities					
1. Factories Act:					
Manufacturing industry	3 520	3 710	3 520	3 580	3 480
Construction industry	3 650	3 540	3 330	3 460	3 530
2. Regulation of Railways and Railway Employment (Prevention of Accidents) Acts†	2 790	3 010	2 770	2 920	2 920
3. Mines and Quarries Act:					
Coal Mines‡ **	20 450	24 610	19 350	20 900	19 970
Quarries‖ **	6 140	4 690	3 900	3 730	3 400
4. Agriculture§	—	1 970	1 890	1 800	1 800
Other authorites					
5. Merchant seamen (non-fatal accidents only)¶	—	—	1 550	1 560	1 320

* Not all accidents for which rates are given in this Table are compulsorily reported.

†Incidence rates over-estimate the true values by approximately 10 per cent although they give a fair indication of trends. Accidents to staff employed by British Rail, London Transport, and Freightliners Ltd are included in the numerator. Only employees engaged in the operation of British Rail, London Transport and Freightliner Ltd are included in the denominator.

‡Non-serious figures included relate only to accidents at mines operated by the National Coal Board, which employs 99 per cent of the labour force engaged in coal mining.

§Incidence rates may under-estimate the true values to some extent. Fatal and non-fatal accidents based on notifications accepted by the Department of Health and Social Security under the National Insurance (Industrial Injuries) Act are included in the numerator but the denominator may include some people who would not apply for industrial injuries benefit.

¶Based on numbers of UK domiciled seafarers only.

‖Including opencast coal sites.

**Revised for earlier years.

Sources:

Sector 1 Health and Safety Executive

Sector 2 Department of Transport

Sector 3 Department of Energy; Health and Safety Executive; National Coal Board; Business Statistics Office

Sector 4 Ministry of Agriculture, Fisheries and Food; Department of Agriculture and Fisheries for Scotland

Sector 5 General Council of British Shipping

Source: Health & Safety Statistics 1976

TABLE 15

ALL ACCIDENTS: RATE PER 100,000 AT RISK

1975	1976	1977	1978
9400	8050	7030	10,700

Source: Offshore Safety, p.109.

VII

RISK IN THE NORTH SEA - NORWEGIAN SECTOR

More detailed and more comprehensive studies of risk levels have been carried out for the Norwegian offshore petroleum activities than for any other country or region anywhere. Moreover, Norwegian studies take as their point of departure the need to estimate risk levels prior to making judgements about safety levels and procedures.

In spite of the significantly greater amount of attention given to the risk problem in Norway, the problems of data encountered elsewhere are also found. The Royal Norwegian Council for Scientific and Industrial Research Report, Risk Assessment, A Study of Risk Levels within Norwegian Offshore Petroleum Activities,* states:

> "There are no official statistics which give accident data for the entire offshore oil activity as it is defined in this report. Thus the data presented herein are gathered from different sources such as statistics from official institutions, as well as non-official information..." (p.71)

> "It has been difficult to get accurate information about exposure time or background data (man-hours, number of rigs, etc.) necessary to calculate fatality rates or accident frequencies. The rates and frequencies given in this report are mainly based on estimates as to the amount of exposure to hazards. Hence the figures should not be taken as absolute values. They do, however, give some indications of the experienced risk level" (p.71).

*Cited as Jensen, Vedeler and Wulff, 1979.

1. The Norwegian Continental Shelf Workforce

As in Canada and elsewhere, Norwegian reports state that data on occupational exposure to risk are not reliable. In fact, four different sources of data are available for the Norwegian shelf area from i) the National Bureau of Statistics, ii) the Directorate of Labour Inspection, iii) the Directorate of Labour and, iv) the Norwegian Petroleum Directorate. Variations in definition, coverage and method of collection result in wide divergencies in the different data sources (Jensen,Vedeler and Wulff, 1979).

The study made its own estimates and gives a high and low figure for each year from 1966 to 1978. As shown in Table 16 there has been a rapid growth in the size of the workforce which has been especially large in the period 1975-78.

2. The Safety Record

There have been 82 fatalities (Norwegians and foreigners) in different offshore activities from 1966 up to and including 1978. As shown in Figure 6, the absolute number of fatalities increased sharply over the period.

The distribution of fatalities by phase of activity and location is shown in Table 17. The largest single area of fatality occurrence is in the category of field development involving helicopters.

The distribution of fatalities by location and activity is shown in Table 18. Analysis of these data reveals that about 42% of the 82 fatalities are caused by helicopter crashes and ditching, 21% are caused by what could be called usual industrial work accidents (maintenance,

TABLE 16

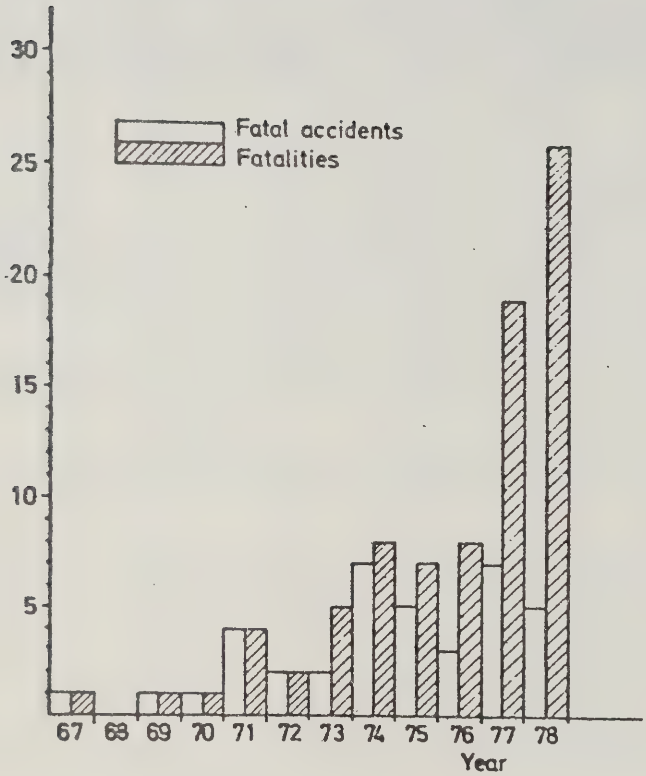
ESTIMATED OFFSHORE WORK IN MAN YEARS, THE NORWEGIAN CONTINENTAL SHELF

		66	67	68	69	70	71	72	73	74	75	76	77	78	Total
Fixed platforms	L												4572	7796	
	H											2633	7858	13390	
Mobile	L	40	140	275	230	360	400	440	325	450	458	391	210	120	
	H	80	280	550	460	720	800	880	650	900	916	782	745	715	
Fixed and mobile	L	40	140	275	230	360	400	440	975	1900	2580	3024	4782	7916	23062
	H	80	280	550	460	720	800	880	1625	3200	4300	3415	8603	14105	39018
Transp etc.*	L	10	30	70	70	100	100	110	320	452	712	1138	1780	1733	
	H	20	70	150	140	200	200	220	480	678	1067	1706	2671	2600	
Total	L	50	170	345	300	460	500	550	1295	2352	3292	4162	6562	9649	29687
	H	100	350	700	600	920	1000	1100	2105	3878	5367	5121	11274	16705	49220

Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979, p.83.

FIGURE 6

NUMBER OF FATAL ACCIDENTS AND DEATHS BY YEAR ON THE NORWEGIAN CONTINENTAL SHELF (PETROLEUM ACTIVITY)



Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

TABLE 17

FATALITIES BY PHASE AND LOCATION ON THE NORWEGIAN CONTINENTAL SHELF

(PETROLEUM ACTIVITY)

TIME PERIOD 1966 TO 1978

Phase / Location	Exploration	Field development	Production	Storage & transp.	Closing & removal	Unallocated	Total
Fixed platform		13	5				18
Mobile platform	10					6 Deep Sea Driller	16
Supply ships		1	1		1		3
Crane vessels/ barges		5					5
Pipelaying vessels		3					3
Helicopters	4**	24	6*				34
Others	1					2	3
Total	15	46	12		1	8	82

Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

TABLE 18

FATALITIES BY LOCATION AND ACTIVITY ON NORWEGIAN CONTINENTAL SHELF

(PETROLEUM ACTIVITY)

TIME PERIOD: 1966 TO 1978

Location / Activity	Fixed plat-form	Mobile plat-form	Supply ships	Crane vessels/ barges	Pipe-laying vessels	Heli-copters	Others	Total
Maintenance/ testing		2						2
Construction	10			1				11
Drilling		3						3
Production process								0
Diving		5		1	1		1	8
Crane operations	4							4
Anchor handling			1					1
Transp to/from/ between locations			1		1	34		36
Emergency evacuation	3	6						9
Others	1		1	3	1		2	8
Total	18	16	3	5	3	34	3	82

Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

construction and crane operations); 11% occurred during emergency evacuation (including the grounding of the Deep Sea Driller); 10% are diver accidents; 4% occurred during drilling operations and there is a miscellaneous category of 12% (Jensen, Vedeler and Wulff, 1979).

3. Fatality Rates

The Norwegian offshore industry has a fatality rate for the period 1966-78 in the range of 1.7 to 2.8 fatalities per 1,000 man years. If helicopter accidents and the Deep Sea Driller grounding are excluded the rate drops to the range of 0.85 to 1.4 fatalities per 1,000 man years.

The cumulative fatality rate for total Norwegian offshore activity is shown in Figure 7. A frequency plot (not cumulative) of the fatality rate is shown in Figure 8.

4. Comparison with the United Kingdom

A comparison with United Kingdom continental shelf fatality rates is shown in Figure 9. The declining trend in the U.K. data falls within the range of estimates for the Norwegian sector from 1970 onwards.

5. Comparison with the Norwegian Chemical Industry

It is reported that,

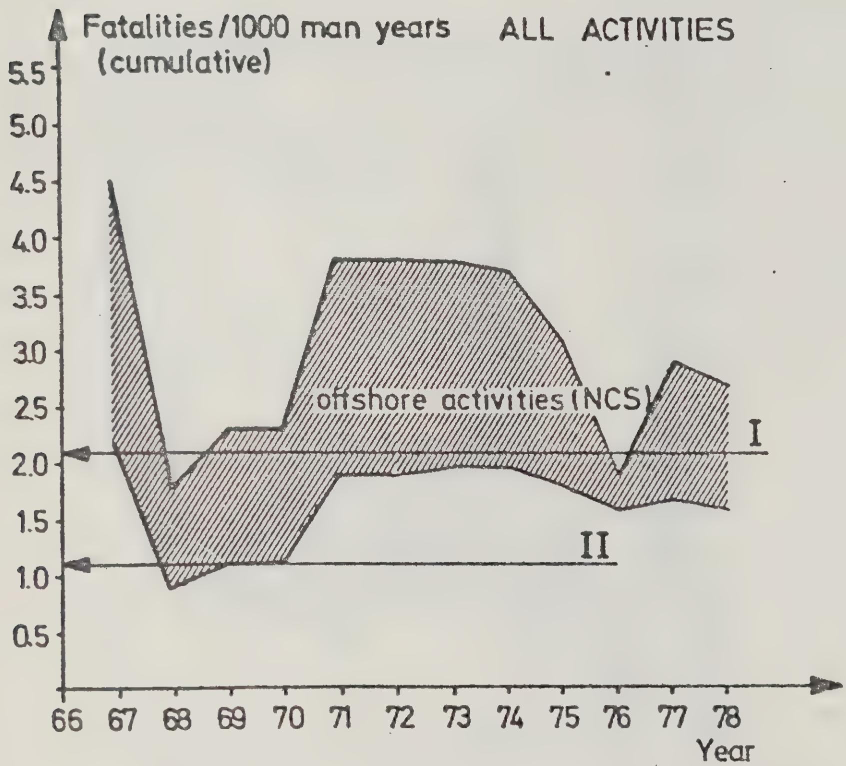
> "Within the Norwegian chemical industry, about 30,000 man years have been performed each year in the time period 1973 to 1978. The number of fatalities has varied from 7, in 1976, to 1, in 1977 and 1975. In these five years, 20 persons have lost their lives in occupational accidents. The average fatality rate for this period of time has been 0.13 fatalities per 1,000 man years. Only 65% of the employees are workers and if the administrative personnel are excluded, the "comparable" fatality rate for the chemical industry in this period has been 0.2 fatalities per 1,000 man years" (p. 86).

FIGURE 7

ESTIMATED FATALITY RATE (CUMULATIVE).

ALL PETROLEUM RELATED ACTIVITIES ON THE

NORWEGIAN CONTINENTAL SHELF



I: Shows the average for the entire period

II: Shows the average for the entire period when excluding Deap Sea Driller and helicopter accidents

---

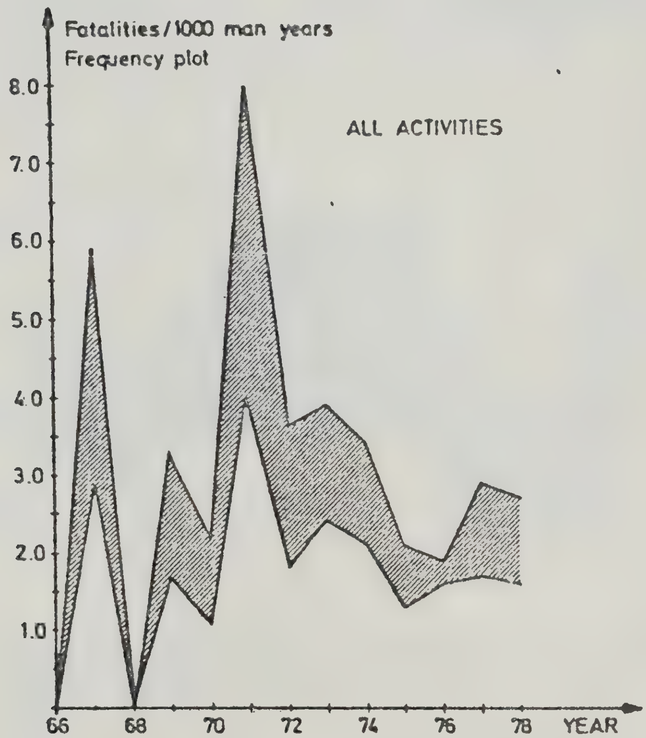
* Cumulative means ,in this context,that the fatality rate for a specific year is based on all the deaths and the total amount of offshore work up to and including that year.

Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

FIGURE 8

FREQUENCY PLOT OF ESTIMATED FATALITY RATE.

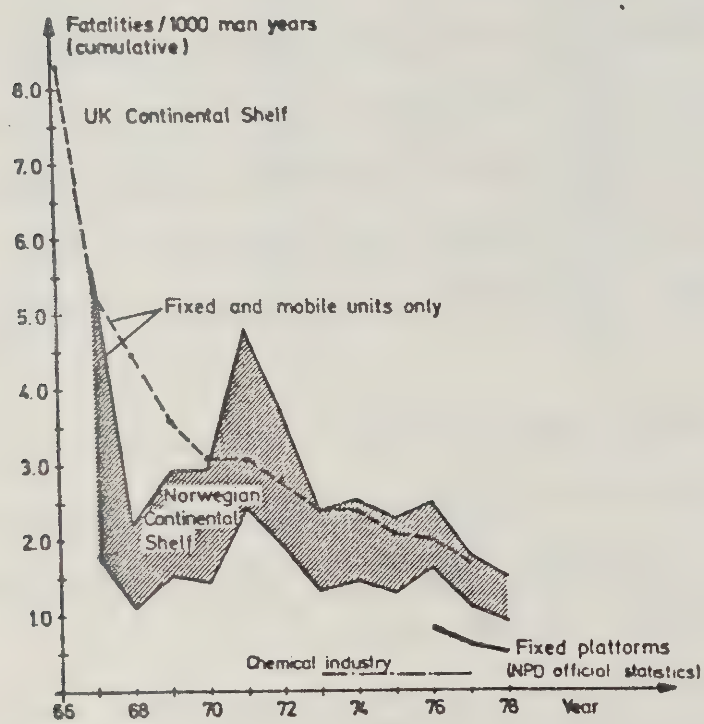
ALL PETROLEUM RELATED ACTIVITIES ON THE NORWEGIAN CONTINENTAL SHELF



Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

FIGURE 9

ESTIMATED CUMULATIVE FATALITY RATE FOR MOBILE AND FIXED PLATFORM ACTIVITIES ON THE UK AND THE NORWEGIAN CONTINENTAL SHELVES.



Source: Jensen,S.B., Vedeler, B., and Wulff,E. Risk Assessment, 1979.

6. Injury rates

Injury rates for the Norwegian shelf are shown in Table 19. These data are for mobile rigs only. There is a great deal of year to year variation, but there has been a clear drop from the higher rates in the first two years (1966 and 1967).

There is difficulty in interpreting these data because the definitions of "injury", "accident" and "occupational injury" are not given.

Comparisons are made between injury rates on mobile drilling rigs, fixed installations and for certain other industries in Table 20. For some of these data at least the definition of an injury is time lost of 11 days or more.

The figures for the other industries have been adjusted upwards by the exclusion of administrative and other non-worker employees from the total workforce at risk. The adapted figures are shown in parentheses.

The Norwegian study concludes that

> "injury frequency on fixed and mobile platforms is comparable to landbased activities such as mining, wood-conversion, etc. Injuries seem to be more frequent on mobile drilling rigs than on fixed installations. Probably, the drilling activity produces the higher injury frequency on mobile rigs. Thus, to reduce the work accident frequency the drilling activity should be studied more closely."

TABLE 19

OCCUPATIONAL INJURY* RATE NORWEGIAN CONTINENTAL SHELF 1966-1978 MOBILE RIGS

Year	Total number of injuries	Activity: Man years	Injuries per 1,000 man years	Injuries per 1 million man-hours
1966	13	39	333	166
1967	50	210	238	119
1968	19	407	47	24
1969	29	255	113	57
1970	43	377	114	57
1971	21	355	59	30
1972	57	568	100	50
1973	49	480	102	51
1974	108	675	160	80
1975	83	748	111	55
1976	104	778	134	67
1977	112	745	150	75
1978	119	715	166	83

*Definition of "occupational injury" not given.

Source: Jensen, S.B., B. Vedeler and E. Wulff 1979. Risk Assessment, p.90.

TABLE 20

ESTIMATED NUMBER OF INJURIES PER 1,000 MAN YEARS

WITH LOST TIME OF 11 DAYS OR MORE.

Industry / YEAR	Total activity on fixed installations		Total activity on mobile drilling rigs		Mining*	Forestry*	Wood-conversion*	Food-stuff* production	Frigg-** field
	L	H	L	H					
1976	20.2	28.3	33.5	46.9					
1977	15.7	21.9	37.5	52.5	42 (57)	62	35 (45)	21 (27)	
1978	11.4	16	41.5	58.1					23

L low estimate, 25% of total recorded and H high estimate, 35% of total recorded. Numbers in parenthesis are adjusted figures.

(*Source: Occupational injury statistics, Directorate of Labour Inspection)

(**Source: Elf, private communication)

VIII

RISK IN THE EASTERN CANADA OFFSHORE AREA

1. Data Requirements

As shown in Section I of this report, a historical approach to risk estimation requires data on numbers of injuries and fatalities per unit time of exposure. Data on numbers of injuries and fatalities is available from the Worker's Compensation Boards in Newfoundland and Labrador and Nova Scotia. There are no data that are satisfactory on time of exposure since this has to be based on counts of numbers of people working offshore and the length of time worked by each person.

In the absence of this data estimates have been made working from the number of MODU's in the study area and making assumptions about the workforce needed on each.

2. Number and Type of Mobile Drilling Unit (MODU) in the Area

The number of MODU's operating in the study area can be determined from published well history data. The Canadian Oil and Gas Lands Administration (COGLA) publishes a listing of Exploratory Wells Drilled in the Canadian Offshore which is updated frequently to include new drilling and wells re-entered. Table 21 summarizes the data for the period 1970 to 1983.

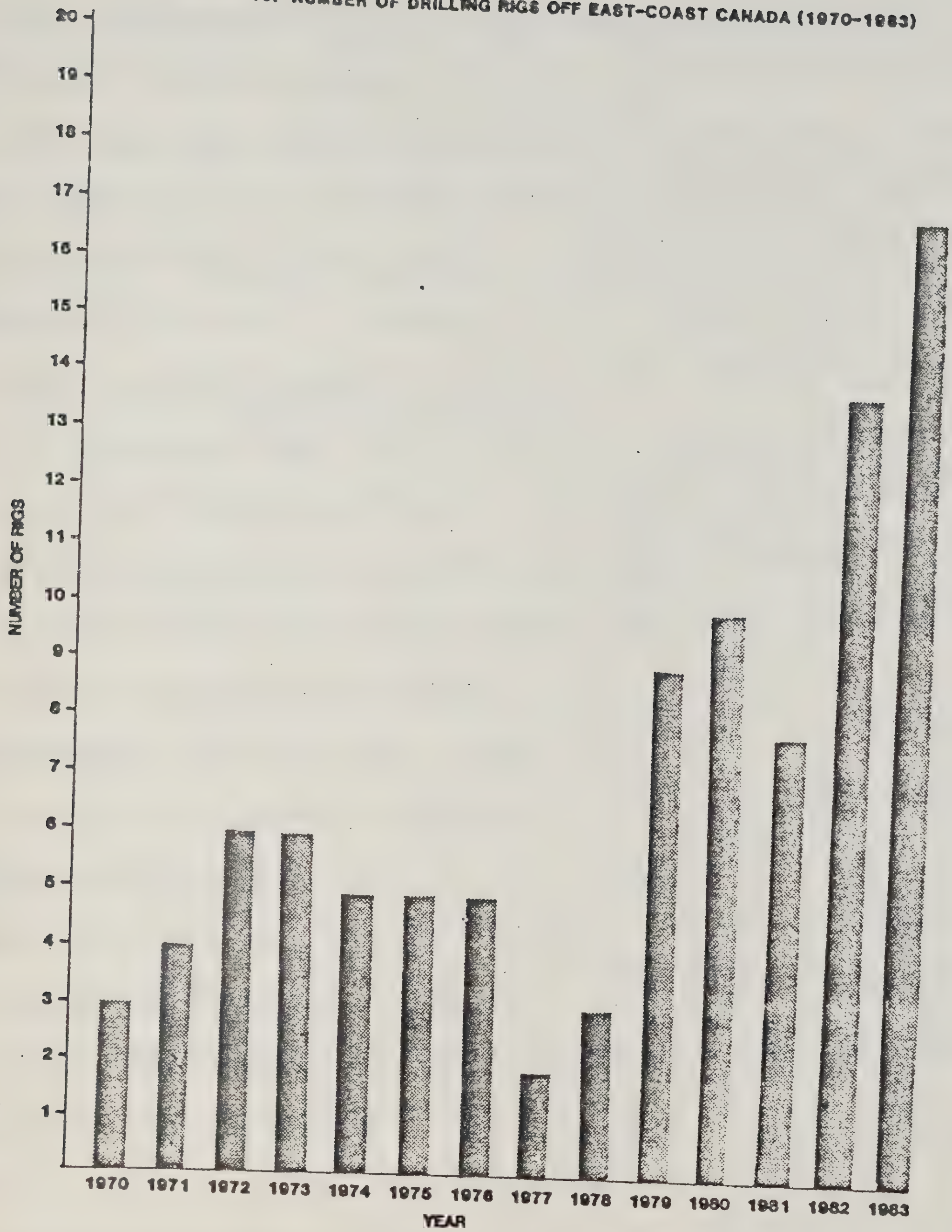
The number of rigs operating in each year 1970-83 is shown in Figure 10. Most of the rig fleet operates in Canadian waters for part of the year only.

TABLE 21

NUMBER AND TYPE OF THE MODU FLEET OPERATING IN EASTERN CANADA OFFSHORE DURING 1970-1983

		Loss Rate in World Wide Operations
Semi-Submersibles	15	0.84%
Drill Ships (including Barges)	12	0. (to 1980)
Jackups	6	1.9%
Total	33	

FIGURE 10. NUMBER OF DRILLING RIGS OFF EAST-COAST CANADA (1970-1983)



3. Estimate of Rig-years of Experience in the East Coast Area

Rig years of operation are calculated from the records of exploratory wells drilled in the study area as reported by COGLA. Commencing January 1, 1970 the number of days drilling has been counted. It is not possible to determine from the COGLA data exactly how many days the MODU's are actually drilling and therefore require a full crew aboard. Assumptions have been made according to industry practice. Days are counted between the SPUD date (well opening) and the date of the release of the rig from the well. To take into consideration the fact that a full crew is required from preparation for SPUDDING two days are added prior to the actual SPUD date.

Time intervals often appear between the withdrawal from one well before another is opened. If the time between the release date and the SPUD date of the rigs next drill is two weeks or less, this time is considered to be drilling time for the purposes of calculating workforce on the rig. Two weeks is assumed to be a reasonable time to reflect difficulties in moving from one location to the next, weather delays, anchoring problems or other delays in SPUDDING the next well. If the period is greater than two weeks it is assumed that the rig did not carry its full complement of people and this time is therefore excluded from the count of rig days. The count recommences two days prior to the next SPUD date.

Two rigs (BAWDEN Rig 9 and Rig 14) operated on Sable Island between 1971 and 1973. Although treated by COGLA as part of the eastern Canada oil explorations, the drilling used land-based rigs and these are therefore excluded from the MODU rig years used in this study. However, two rigs

operating north of 60° latitude for part of the year 1979 are included although not reported in COGLA well history data.

The total rig days and rig years of operation for 1970-83 have been counted and are presented in Table 22. The bar chart in Figure 11 depicts the division of rig years between Nova Scotia, and Newfoundland and Labrador.

4. Estimate of the Study Area Workforce

No summary data exist for the number of people employed on MODU's in the study area. The data may exist in raw form in payroll records of a number of different companies, but time limitations prevent any possible use of such information even if it were found to be accessible.

In order to estimate the workforce two measures have been made. The higher and upper bound estimate is based on the maximum number of people that sleeping accommodation is provided for on each operating rig. The annual directory of marine drilling rigs published in Ocean Industry gives design specifications for all rigs. The Ocean Industry figure for quarters on board each MODU is assumed to represent the maximum number of people. The minimum number would consist of a skeleton crew necessary for maintaining the rig and moving it from one location to another. A somewhat arbitrary assumption of 50% of the maximum number has been chosen.

The upper and lower bound estimates are made by multiplying the numbers on board by the number of rig days of operation as defined above and listed in Table 22. For example, if a rig can house 90 people and operated for all 365 days of a particular year, then this constitutes an upper bound

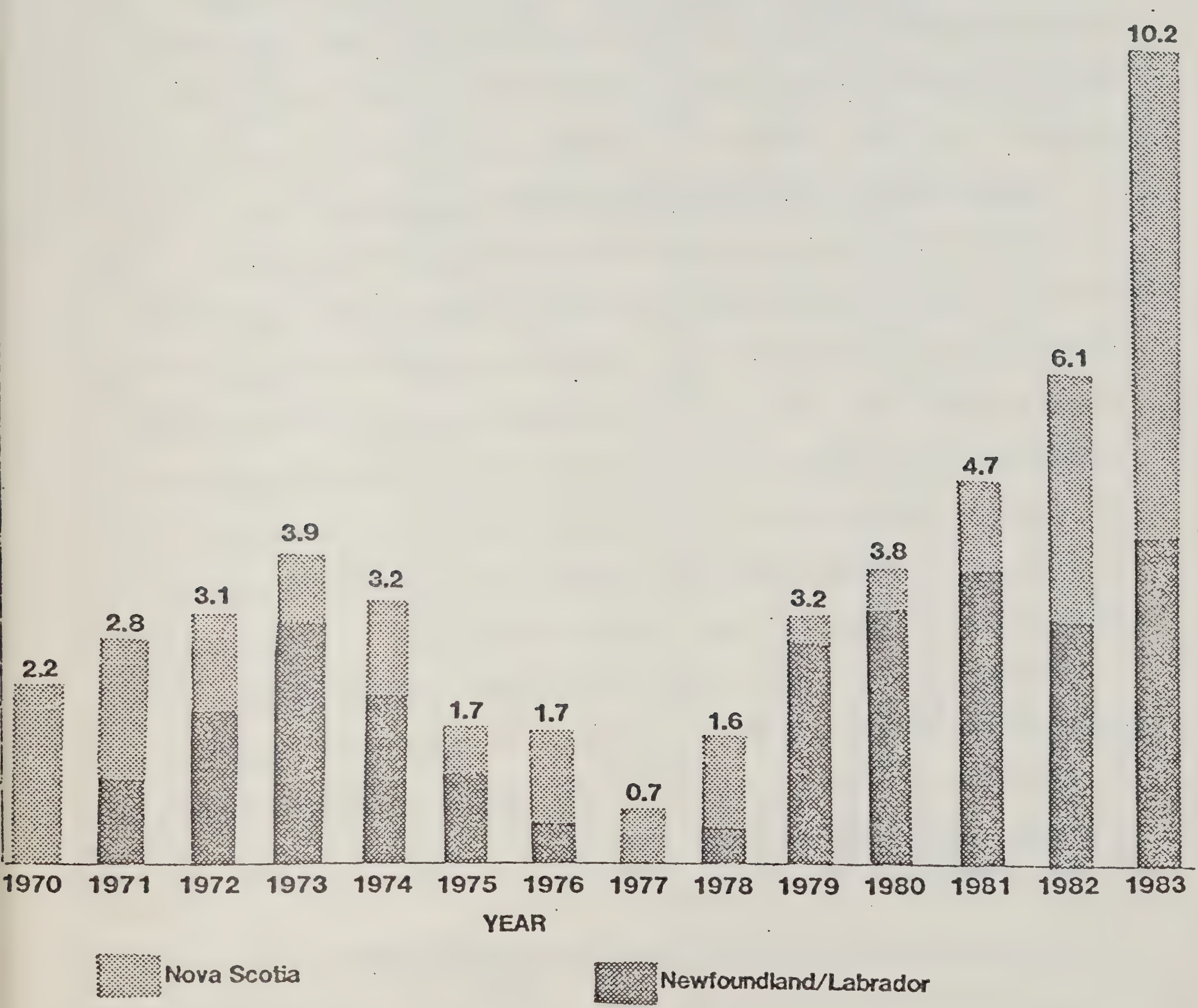
TABLE 22. NUMBER OF DRILLING DAYS OFF EAST-COAST CANADA (1970-1983)

NAME OF RIG	TYPE	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980		1981		1982		1983	
SEDNETH 1	(SS)	365		284	77	84	280		249																				
SEDCO H	(SS)	338		357		366		338	28	273	26			294		81													
WODECO II (Barge)	(DS)	210																											
SEDCO I	(SS)				287		351		346		343		4																
TYPHOON	(DS)				86																								
SEDCO J	(SS)						46		357	176	133	207	81		63														
PELICAN	(DS)								84		106		110		64						81		84						
NAVDRILL	(DS)										123		126																
SEDCO 445	(DS)												74																
PETREL	(DS)													46	63						64						67		46
GULFTIDE	(J)															154		315		168									
ZAPATA UGLAND	(SS)													91							83		366		316		306		296
BEN OCEAN LANCER	(DS)																	112	60		74				86				
PELERIN	(DS)																		102		91		63		91		106		86
NEDRILL II	(DS)																						106				112		81
DISCOVERER SEVEN SEAS	(DS)																				123								
SEDCO 709	(SS)																				207		193				86	322	42
GLOMAR ATLANTIC	(DS)																				161		60						
SEDCO 707	(SS)																				130								
SEDCO 706	(SS)																						291		365		280		360
SALENERGY IV	(J)																					63							
ROWAN JUNEAU	(J)																					140		365		365		329	
PACHORSE I	(DS)																								91		91		49
OCEAN RANGER	(SS)																						21		365		46		
JOHN SHAW	(SS)																										4	240	74
BOW DRILL I	(SS)																							28		365		319	
ZAPATA SCOTIAN	(J)																									256		365	
VINGLAND	(SS)																									133		350	
WEST VENTURE	(SS)																										14		365
GLOMAR HIGH ISLAND IX	(J)																											77	
BOW DRILL II	(SS)																											119	
SEDCO 710	(SS)																												154
GLOMAR LABRADOR	(J)																											39	
TOTAL DAYS OF DRILLING		812		641	420	448	676	336	1078	448	726	207	403	431	182	245		427	162	169	894	197	1203	393	1315	1119	1083	2169	1515
TOTAL NUMBER OF RIGS (33)		3		4		4		5		5		5		5		2		3		10		10		8		14		17	
RIG-YEARS		2.2	0.0	1.7	1.1	1.2	1.9	0.9	3.0	1.2	2.0	0.6	1.1	1.2	0.5	0.7	0.0	1.2	0.4	0.5	2.7	0.5	3.3	1.1	3.6	3.1	3.0	6.0	4.2
TOTAL RIG-YEARS		2.2		2.8		3.1		3.9		3.2		1.7		1.7		0.7		1.6		3.2		3.8		4.7		6.1		10.2	

SS - Semi-Submersible
J - Jackup
DS - Drillship

Left hand column refers to drilling off Nova Scotia.
Right hand column refers to drilling off Newfoundland and Labrador.

FIGURE 11. RIG-YEARS OF DRILLING OFF EAST-COAST CANADA (1970-1983)



estimate. For shorter periods of operation the estimate is reduced proportionately. Thus the yearly total in Table 23 represented the number of people at risk on a yearly basis. These are correctly regarded as people-equivalents since the number of individuals who spend some time on the rig is probably twice as large, because the companies usually have one complete crew on the rig and one on shore at any one time.

5. Comparison of Study Estimates to Partial Reported Data

Partial data for two sources provide a check on the method of estimation used. The Petroleum Directorate of Newfoundland and Labrador provided data on total person-hours worked on the MODU's contracted by Petro Canada in 1982. The reported 340,920 person-hours corresponds to 78 people working 365 daily shifts of 12 hours each. The study method of calculating the number of persons working a full year yields 83 as an upper bound estimate and 41 as the lower bound estimate. The figure of 78 reported thus falls within the estimated range towards the upper end.

A further comparison is made from statistics provided to the Newfoundland and Labrador Petroleum Directorate by the Mobil Oil Company. The Mobil data consist of composite accident frequency rates and numbers of lost-time accidents for the years 1980-82.

The frequency rate is calculated as

$$\text{Frequency rate} = \frac{\text{number of disabling injuries} \times 10^{-6}}{\text{person-hours worked}}$$

Since the number of disabling injuries is known, the person-hours worked can be calculated. Although there are some difficulties in

TABLE 23

MAXIMUM NUMBER OF PERSONS ESTIMATED TO BE AT RISK IN THE EASTERN CANADA OFFSHORE AVERAGED OVER ENTIRE YEAR[1]

Year	Persons at risk*	Nova Scotia	Newfoundland
1970	180	180	0
1971	252	154	98
1972	266	107	159
1973	309	80	229
1974	241	93	148
1975	119	33	86
1976	142	103	39
1977	58	58	0
1978	148	104	44
1979	290	39	251
1980	326	43	283
1981	423	85	338
1982	541	269	272
1983	924	536	388

*This number is interpreted as follows: i.e., for the year 1970 the equivalent of 180 persons in total worked on the MODU's operating in the study area each day of that year (180 persons working 365 daily shifts of 12 hours each).

Nova Scotia includes the following drilling areas: Scotian Shelf, Gulf of St. Lawrence and the Bay of Fundy.
Newfoundland includes: Grand Banks, Labrador Shelf, North East Newfoundland Shelf, Labrador Deep and Atlantic Deep.

1. These estimates are approximations only as described in the text. The table shows the results of calculations made, but should not be taken to imply accuracy to three significant figures. The same caveat applies to Tables 24, 25 and 27.

interpretation of the Mobil Oil Company data, the comparisons made in Table 24 are moderately encouraging. The estimate from Mobil accident frequency data falls very close to the lower bound estimate of the persons on the MODU's in these three years.

6. The Safety Record

It seems that reasonable confidence can be placed in the method of estimating the MODU workforce in the study area. Total person-hours for each year are calculated by multiplying the estimated number of persons on rigs by 365 daily shifts of 12 hours each. The upper and lower bound estimates so calculated for the years 1970-83 are provided in Table 25. When coupled with data on accidents reported from Nova Scotia and Newfoundland, these figures permit accident rates to be calculated.

Nova Scotia

Data supplied by the Worker's Compensation Board of Nova Scotia are shown in Table 26, by Industrial Rate Class for 6 years (1977-1982). During this period, there are no reported fatalities in oil explorations in the Nova Scotia area of the offshore developments. This compares with 21 fatalities in fishing, 4 in mining (Class 1 industries) and 3 in building construction. Lack of information about the total workforce in these industries prevents comparison of the fatality rate. It is clear, however, that one single large-scale accident can dramatically alter both the total number of fatalities and the rate. A small sample of years is not sufficient to provide a basis for making estimates of the probability of infrequent events such as are represented by the loss of the Ocean Ranger with 84 lives.

TABLE 24

COMPARISON OF ESTIMATES OF PERSONS AT RISK FOR YEARS 1980-82 FOR MODU'S CONTRACTED BY MOBIL OIL COMPANY

	Study Estimate		Estimate Derived from Reported Statistics
	Upper Bound	Lower Bound	
1980	162	81	85
1981	275	137	137
1982	157	79	74
Total	594	297	296

TABLE 25

TOTAL PERSON-HOURS WORKED IN THE EASTERN CANADA OFFSHORE AREA

YEAR	UPPER ESTIMATE	LOWER ESTIMATE
1970	788,400	394,200
1971	1,055,580	527,790
1972	1,165,080	582,540
1973	1,353,420	676,710
1974	1,055,580	527,790
1975	521,220	260,610
1976	621,960	310,980
1977	254,040	127,020
1978	648,240	324,120
1979	1,270,200	635,100
1980	1,427,880	713,940
1981	1,852,740	926,370
1982	2,369,580	1,184,790
1983	4,047,120	2,023,560

TABLE 26
ACCIDENTS REPORTED BY NOVA SCOTIA WORKER'S COMPENSATION BOARD (1977-1982)

Type of Claim	All Accidents	IRC-114†† Oil Explor.	IRC-1 Mining	IRC-200 Fishing	IRC-700 Bldg. Constr.	IRC-943 Diving
			1982			
Fatal	26	-	-	4	-	-
P.D.*	94	1	2	1	3	-
T.D.**	11,478	51	74	318	679	-
M.A. only¶	16,795	43	115	138	1,030	-
Other†	1,307	8	14	21	82	-
	29,700	103	205	482	1,794	-
			1981			
Fatal	20	-	-	2	2	-
P.D.	196	-	3	1	5	-
T.D.	11,986	15	113	335	700	-
M.A. only	18,365	31	238	178	1,191	-
Other	1.433	1	17	23	94	-
	32,000	47	371	539	1,992	-
			1980			
Fatal	19	-	2	6	-	-
P.D.	41	-	-	1	3	-
T.D.	12,706	15	142	298	673	-
M.A. only	18,557	28	280	141	1,138	-
Other	1,514	6	22	14	105	-
	32,837	49	446	460	1,919	-
			1979			
Fatal	43	-	-	5	-	-
P.D.	62	-	1	1	1	-
T.D.	11,998	17	153	255	736	-
M.A. only	19,613	37	198	116	1,312	-
Other	1,391	11	20	16	125	-
	33,107	65	372	393	2,174	-
			1978			
Fatal	19	-	2	3	-	-
P.D.	148	-	4	5	7	-
T.D.	11,271	19	153	266	784	-
M.A. only	17,973	30	192	116	1,317	4
Other	1,404	6	13	19	125	1
	30,815	55	364	409	2,233	5
			1977			
Fatal	21	-	-	1	1	-
P.D.	49	-	1	2	4	-
T.D.	10,997	19	188	251	799	-
M.A. only	17,192	26	156	87	1,311	-
Other	1,366	14	16	13	112	-
	29,625	59	361	354	2,227	-

*Permanent Disability **Temporary Disability ¶Medical aid only
†non-compensable.††Industrial Rate Class.

The number of disabling injuries is also shown in Table 26. Only one permanent disability is reported in oil explorations for the 6 year period. This compares with 23 permanent disability injuries in building construction and 11 each in fishing and mining (Class 1 industries). Comparison of frequency rates is not possible in the absence of data on total workforce in these industries.

The frequency of disabling injuries in oil explorations (all except 1 are temporary disabilities) is shown in Table 27 in units of 1 million person-hours. 1 million person-hours is equivalent to 500 person-years, assuming that there are 2,000 person-hours per year.

Comparing the rate in Table 27 (for Nova Scotia) with the rate in Table 19 (for Norway), shows the rates to be roughly the same order of magnitude within the limits estimated for person-hours worked. It is not known, however, if the reporting requirements for "injuries" in the Norwegian data correspond to that for disabling injuries in the Nova Scotia Workmen's Compensation Board data.

These data do not permit a conclusion to be drawn that accident rates are clearly lower or higher in Norway compared with Nova Scotia. The most that can be said is that the rates appear similar. No radically different rates have been detected.

Newfoundland

Accident data for Newfoundland have been supplied by the Petroleum Directorate, (Table 28) and by the Worker's Compensation Board (Table 29). Average frequency rates as reported by the Petroleum Directorate are of the

TABLE 27

FREQUENCY OF DISABLING* INJURIES IN OIL EXPLORATIONS - NOVA SCOTIA 1977-1982

Year	Upper Limit Frequency	Lower Limit Frequency
1977	74	148
1978	42	84
1979	99	198
1980	80	160
1981	20	40
1982	44	88

*Includes permanent disabilities and partial disabilities but does not include cases where medical aid only was given.

Injuries per 1 million person-hours.

Accident data from Table 26 for Oil explorations includes onshore and offshore workers.

Maximum Person-hours calculated using equivalent persons figures (i.e.,working 365 daily shifts of 12 hours each) from Table 23.

Lower estimate of person-hours is 50% of maximum.

TABLE 28

REPORTED FREQUENCY RATES FOR LOST-TIME ACCIDENTS OR DISABLING INJURIES

NEWFOUNDLAND. 1980-1983

Year	Rig Name	Average frequency rate for months worked	Range for months reported
1980	Sedco 706	56.48	0 - 217.7
	Zapata Ugland	39.58	0 - 167
	Ocean Ranger	81.33	0 - 183.
1981	Sedco 706	0	0
	Zapata Ugland	18.5	0 - 106
	Ocean Ranger	27.36	0 - 141
1982	Sedco 706	34.52	0 - 105.7
	Zapata Ugland	4.25	0 - 51
	Ocean Ranger	N.A.*	N.A.
	West Venture	55.67	55.67
	Pac Norse I	29.92	0 - 55
	Neddrill II	8.47	0 - 35.7
	Pelerin	48.95	0 - 84.9
1983	Sedco 706	19.1	0 - 96.3
	Zapata Ugland	2.67	0 - 32
	West Venture	80	33 - 161.9
	John Shaw	50.7	0 - 62.1

*Frequency for Ocean Ranger was not available.

Source: Petroleum Directorate, Newfoundland and Labrador.

TABLE 29

ACCIDENTS REPORTED BY NEWFOUNDLAND AND LABRADOR WORKER'S COMPENSATION COMMISSION (1979-83)

Type of Accident	Year	Class 1.5 Offshore Oil Exploration	Class 1 Mining (Excl. 1.5)	Class 4 Constr.	Class 5.5	Class 7.2 Fishing
	1983					
Fatal		*	*	*	*	1
Lost Time		90	98	*	5	197
M.A.¶		67	295	*	4	47
Total Acc.		219	463	1278	24	258
	1982					
Fatal		**	*	*	*	1
Lost Time		58	81	*	39	210
M.A.		46	353	*	13	57
Total Acc.		137	449	1247	69	310
	1981					
Fatal		*	*	*	*	1
Lost Time		40	160	*	27	188
M.A.		26	498	*	20	40
Total Acc.		116	774	910	65	240
	1980					
Fatal		*	*	*	*	1
Lost Time		46	151	*	22	116
M.A.		25	461	*	8	29
Total Acc.		95	707	946	45	186
	1979					
Fatal		*	*	*	*	1
Lost Time		25	186	*	7	166
M.A.		10	531	*	6	59
Total Acc.		50	831	1150	25	249

¶ Medical Aid Only
* No value given
** Although 84 lives lost on Ocean Ranger only 66 claims reported to W.C.C.

same order of magnitude as seen in Nova Scotia and Norway. However serious doubt is cast on the value of such average frequency data when the range is large. For example, Sedco 706 in 1980 reports an average of 56.48 accidents per month, but the monthly values range from zero in each of 7 months to 217.7 in May. It is conceivable that such extreme variations in numbers of accidents might be caused by radical changes in conditions such as severe deck icing. Incomplete reporting is the more likely explanation. The data for 1980 reported in Table 28 are incomplete, because it is known from other sources that there were 8 rigs operating in Newfoundland waters in 1980. (See Table 23).

The frequency of lost time accidents in the Newfoundland and Labrador areas is shown in Table 30 for the years 1978-83. The estimates are generally low compared with those for Norway (Table 19) but again the lack of accuracy in the data and doubts as to their strict comparability permit no more than the conclusion that they are not radically different.

TABLE 30

FREQUENCY OF LOST TIME ACCIDENTS IN OFFSHORE OIL EXPLORATIONS.

NEWFOUNDLAND AND LABRADOR (1979-83)

Year	Upper Limit Frequency	Lower Limit Frequency
1979	23	46
1980	37	74
1981	27	54
1982	49	98
1983	53	106

Injuries per 1 million person-hours.

Maximum person-hours calculated using equivalent persons figures (i.e. number of persons working 365 daily shifts of 12 hours each) from Table 23.

Lower estimate of person-hours is 50% of maximum.

IX

CONCLUSIONS

1. The Data Situation

Risk analysis of offshore oil explorations by the historical method is severely handicapped by data limitations. These include:

i) the short period of record such that average rates are subject to wide variation as a result of the occurrence of a small number of rare events;

ii) incompleteness of reporting;

iii) systematic bias in figures reported to regulatory bodies and worker's compensation boards.

When cross national comparisons are made, these data limitations are further increased by lack of standard definitions and reporting classes.

If accident and fatality rates are considered to be important in Canada as a means of assessing risk, monitoring safety performance and providing comparable data, then a single accident reporting form collected by a single agency with the authority to ensure that the reports are complete and accurate would provide the information needed to gain better understanding of the causes of accidents and the risks faced by offshore workers. If such an innovation were made in addition to the existing reporting requirements for companies in the offshore industry, compliance would be less than enthusiastic and the results would correspondingly be likely to suffer. Improvement and simplification of existing reporting is what is required.

There is an important international aspect to data reporting. If data from the several nations engaged in offshore oil explorations are to be more comparable, some standardization of reporting categories and definitions is desirable. This is a task more appropriately undertaken by an international intergovernmental body such as the International Labour Organization.

2. The Risk of Fatality

Deaths in the offshore oil and gas industry can be divided into two populations. Those associated with routine operations are termed "industrial accidents". Those associated with major accidents are termed "marine disasters". Fatalities in the first category occur more often in small numbers--often as single fatalities and almost always in groups of less than 20 deaths at any one time. Fatalities in the second category are associated with a large number of simultaneous fatalities as in the case of the Alexander Kielland (North Sea) and the Ocean Ranger (Canadian east coast).

Marine disasters are associated with the total loss of a MODU. There have been 63 total losses reported in the period 1956-80 (see Table 4). Only a small number of these have resulted in a large loss of life.

Of the 486 lives lost worldwide in the period 1970-82, a total of 349 or 72% have been lost in the four major disasters listed in Table 6.

Let it be assumed that large losses of life may be expected at the rate of four times in every 63 total loss accidents, or once every 16 total loss accidents. If one total loss occurs for every 81.3 rig years (Table 4)

then it may be estimated that a total loss accident associated with a high loss of life--that is, a marine disaster, may be expected to occur once every 1,300 rig years. Given a record of 5,125 rig years of operation in 1956-80 (Table 4) four major loss of life accidents is close to the expected number.

How does this translate into expected risk of fatality for an offshore rig worker? If all persons on board a rig involved in a total loss accident are assumed to be lost (not likely to be always the case) then the chance of being killed for a person who spends a whole year on a rig is .0008, or 1 in 1,250. If the person (as is commonly the case) is on the rig only half of the time then the risk of being killed in any given year is .0004 or 1 in 2,500.

This compares with the probability of being killed of 1 in 166 calculated in Section IV on the basis of assuming that all total loss accidents involve the loss of all hands on board. Certainly this has been the limited Canadian experience. In 49 rig years of operations there has been one total loss accident and all lives were lost.

Estimates such as these demonstrate the twin difficulties, on the one hand, of extrapolating from a short period of record, and on the other hand, of applying worldwide data to eastern Canada offshore conditions. The risk estimate of a worker being killed in a single year of .006 made in Section IV is almost certainly too high. The risk estimate of .0004 is probably too low. Note that it is very close to the risk to the population of the United States from all accidents which is reported as 1 in 2,000 in Table 7. This would suggest that being a worker on an offshore rig is no more dangerous

than the life of an average person in the United States. This is a little hard to accept.

To say that the risk of fatality of an offshore oil rig worker in eastern Canada is (on an annual basis) between .006 and .0004 is not a very precise estimate. It is the most that can be said on the basis of present data.

Fatality rates for the United States, the United Kingdom and Norway are listed in Table 31. These rates are not strictly comparable, but what is surprising about them is the relatively narrow spread considering the data deficiencies. In probability terms the chance of being killed for an offshore worker ranges from .002 (U.K. 1974) to .00002 (U.S.A. 1979), not counting the record of zero fatalities in the U.K. in 1978.

3. Injury Rates

Accidental injuries can be compared less easily between countries than fatality rates. No injury rates have been found for U.S. offshore areas. Comparisons cannot be made with rates for the United Kingdom North Sea area which are given in "serious accidents per 1,000". The closest comparison that can be made is between eastern Canada and Norway as shown in Table 32. While the years for which data are available do not coincide (except for 1977 and 1978 for Norway and Nova Scotia) the Norwegian rates are generally of the same order as those in the eastern Canada offshore area.

This analysis has not been able to establish any major differences in injury rates among the four countries studied.

TABLE 31

COMPARATIVE FATALITY RATES IN OFFSHORE OIL ACTIVITIES IN THE UNITED STATES, THE UNITED KINGDOM AND NORWAY

Year	U.S.[1]	U.K.[2]	Norway[3]
1974	--	2.0	ranges
1975	--	1.5	between
1976	1.13	1.5	1.7 and 2.8
1977	.96	.8	
1978	.85	0	
1979	.62	--	

1. Rate per 1,000 workers per year.
2. Rate per 1,000 employed.
3. Rate per 1,000 person-years.

TABLE 32

INJURIES PER MILLION PERSON-HOURS. NORWAY AND EASTERN CANADA.

	Norway	Eastern Canada			
		Nova Scotia		Newfoundland and Labrador	
		Upper Estimate	Lower Estimate	Upper Estimate	Lower Estimate
1974	80	--	--	--	--
1975	55	--	--	--	--
1976	67	--	--	--	--
1977	75	74	148	--	--
1978	83	42	84	--	--
1979	--	99	198	23	46
1980	--	80	160	37	74
1981	--	20	40	27	54
1982	--	44	88	49	98
1983	--	--	--	53	106

Definitions as given in Tables 19, 27 and 30.

4. Comparisons with other activities

In the United Kingdom it is reported that an offshore worker is about twice as likely to have an accident as a worker in general manufacturing and about half as likely as a miner. Accidents offshore are more likely to be fatal especially in diving activities (Tables 13, 14, and 15). In Norway it is reported that the injury frequency on offshore platforms is comparable to landbased activities such as mining and wood-conversion. (Table 20). In the United States outer continental shelf it is reported that the drilling accident rate is nearly 15 percent lower for marine oil and gas operations than for those on land.

There is no statistical basis for similar comparisons in Canada without resort to inaccessible raw data. Such an analysis could, in theory at least, be made for Canada especially if accident reporting procedures are improved. Given that accident rates in the eastern Canada offshore area do not appear to be significantly different from those reported elsewhere, especially in Norway, there is no reason to suppose that comparisons with other industrial activities would show Canada's offshore oil explorations to be especially more dangerous from an "industrial accident" point of view. Indeed on the basis of limited comparisons it might be judged that offshore drilling and related activities are safer in terms of industrial rates and more dangerous only in terms of the low probability of a "marine disaster".

5. Accidents by Type of Activity

Priority areas for risk reduction can be identified by an examination of those types of offshore activity which result in higher numbers of accidents.

In the Gulf of Mexico it is reported that 42 per cent of the accidents involving fatalities occur in drilling operations, and a further 41 percent in production operations (Table 9). Most fatal accidents are caused by machine or equipment failure (27 per cent), personal accidents (24 per cent) and fires or explosions (19 percent). By comparison helicopter crashes account for only 17 percent of fatal accidents and blowout only 1 per cent.

In the United Kingdom sector of the North Sea, drilling is the single most accident related activity, and the largest number of fatalities is associated with diving (Table 11). There has been only one helicopter fatality reported.

In contrast, in the Norwegian sector of the North Sea, diving has a much lower proportion of fatalities, whereas helicopter accidents account for the largest single fatality class (Tables 17 and 18).

Why is it that in the Gulf of Mexico drilling appears to be more dangerous, and that diving appears to be a special problem for the British and helicopters for the Norwegians? The most likely explanation is that the differences are more apparent than real and are a product of limited periods of record. When experience is short one or two freak events can change the statistical pattern. Only with long time series data are these freak events averaged out into some "normal" rate.

6. Factors in Accident Events

Man-machine systems of all kinds can fail or can operate improperly due to faults in the machines and their design or due to operator-error (commonly called human errors). All accidents are due to human error at some point. Accidents resulting from equipment failure may be traced back to poor or improper design.

Experience shows that in the offshore oil and gas industry, the rapid expansion of the worldwide MODU fleet has been accompanied by substantial improvements in technology. Yet it is clear that things can still go radically wrong as demonstrated in the total loss accidents in recent years. The further application of risk modelling methods such as event- and fault-tree analysis to the design of offshore oil platforms may yield benefits in the prevention of future possible disasters.

The most common cause of accidents whether of the "marine disaster" or "industrial accident" type is operator error. The record shows that the safety record in the offshore oil and gas industry is as good if not better than in comparable industrial activities on land. Accidents at sea, however, are more likely to become serious because of the hostile marine environment in which they may occur. For this reason, a higher level of safety performance should be expected on drilling rigs at sea than on land. There is some evidence, in the United States at least, to suggest that a higher standard of performance is being achieved.

The United States NRC study (1981) makes one very telling point about offshore safety. It reports that operator experience is a key factor.

It was found that 76.5 per cent of all injuries occurred to employees with less than one year on the job, and that 54.8 per cent of all injuries occurred within the first six months of employment.

MODU workers who are in such danger of accident are necessarily a danger to others also. Clearly the proper selection and training of offshore oil workers is a crucial factor in improving safety performance.

In addition to the application of risk modelling and improved worker selection and training, this study of risk indicates that another area of risk reduction that needs close examination is the area called "consequence mitigation". It is an axiom of risk analysis that accidental events can be reduced in frequency but not completely eliminated. Risk management includes the making of preparations to help reduce the effects of accidents when they happen.

X

REFERENCES
LITERATURE CITED AND USED AS REFERENCE MATERIAL

Berg, George G. and David H. Maillie (Eds.) 1981. Measurement of Risks. Plenum Press: New York.

Blumberg, R., J.R. Shaw and S.A. Taher 1972. Selecting an Offshore Drilling Rig in Oceanology (April).

Bruneau, A.A. 1983. Letter to B.R. LeDrew, Ocean Ranger Commission Director of Studies, Sept. 7., concerning "Engineering Design Advisory Committee: Status and Direction". Bruneau Resources Management Ltd.(St. John's).

Burton, I., R.W. Kates and G.F. White 1978. The Environment as Hazard. Oxford University Press: New York.

Canada Dept. of Energy, Mines and Resources, Resource Management Branch 1979. Offshore Exploration. Abridged Version, 8th issue, Report E1-79-4, April.

Canada Ministry of Supply and Services 1980. Oil and Gas Drilling Regulations. P.C. 1979-25, amended by P.C. 1980-2111.

Canada Oil and Gas Lands Administration 1982. Annual Report Department of Energy, Mines and Resources: Ottawa.

Canada Oil and Gas Lands Administration 1983. Drilling for Oil and Gas on Canada Lands. Guidelines and Procedures. Draft of September. Department of Energy, Mines and Resources: Ottawa.

Canada Royal Commission on the Ocean Ranger Marine Disaster 1983. Occupational Health and Safety. Study prepared by A.M. House, H.J. Manson, J.R. Martin and T.M. Rahal. November. Centre for Offshore and Remote Medecine (MEDICOR).

Dick, D. 1982. Safety Technology for Offshore Oil Platforms in High Risk Safety Technology by A.E. Green (ed.). Chapter 2.5. Wiley and Sons:

Eastcoast Petroleum Operators Association 1983. Eastern Offshore News 5:1(March).

Eastcoast Petroleum Operators Association 1983. Eastern Offshore News. 5:2(August).

Ellers, Fred S. 1982. Advanced Oil Platforms in Scientific American. 246:4, pp.37-49.

Heaf, N.J., R.K. Henrywood, and L.R. Wootton 1975. Assessment of the Accuracy of the Design Process for Off-shore Structures in Offshore Structures. Proceedings of the Conference of October 7-8, 1974. Institution of Civil Engineers: London. pp.145-150.

Holland, Ivar and Torgeir Moan 1981. Risk Assessment of Offshore Structures: Experience and Principles. Norwegian Institute of Technology. Unpublished paper presented to POAC, Ottawa, July.

Inhaber, H. 1978. Risk of Energy Production. Report AECB-1149, Revised. Atomic Energy Control Board: Ottawa.

International Labour Organization 1978. Safety Problems in the Offshore Petroleum Industry. ILO: Geneva.

Jensen, S.B., B. Vedeler and E. Wulff 1979. Risk Assessment: A Study of Risk Levels within Norwegian Offshore Petroleum Activities. Report No. 26-27/2. Royal Norwegian Council for Scientific and Industrial Research: Oslo.

Kasperson, R.E. and J.X. Kasperson 1983. Determining the Acceptability of Risk: Ethical and Policy Issues in Risk: Proceedings of a Royal Society of Canada Symposium on the Assessment and Perception of Risk by J.T. Roger and D.V. Bates (eds.). Royal Society of Canada: Ottawa. pp.135-156.

Kreps, Gary A. The Organization of Disaster Response: Some Fundamental Issues in Disasters: Theory and Research by E.L. Quarantelli (ed.). Sage Publications:

LeBlanc, Leonard 1981. Tracing the Causes of Rig Mishaps in Offshore March, pp. 51-62.

Martec Ltd. Evaluation of Emergency Equipment and Sea Rescue Techniques for Use from Mobile Offshore Drilling Units in Canadian Waters. Prepared for the Canada Oil and Gas Lands Administration, Ottawa.

May, Bradley K. 1982. A General Model of Organized Community Disaster Response and Its Applicability to Offshore Oil Platforms. Unpublished paper. Department of Geography, University of Toronto. December.

Moan, Torgeir no date Risk Assessment of Mobile Rig Operations. Norwegian Institute of Technology, University of Trondheim:

1983. 1983-84 Directory of Marine Drilling Rigs in Ocean Industry (Sept).

1983. Offshore Accident Review 1:1 (August).

Offshore Rig Data Services Accidents: Offshore Mobile Drilling Rigs 1955 to Present. Offshore Rig Data Services: Houston, Texas.

Prossin, Albert 1983. The Ocean and Occupational Health in Canadian Family Physician 29:(June), pp.1135-1140.

Rescue Coordination Centre no date The Capsize of the Accommodation Platform, Alexander L. Kielland in the North Sea, 27 March, 1980. Report on the Search and Rescue Operation.

Sage Institute (Edmonton) 1979. Safety in the Oilfields. Report of a Study for Alberta Government, Division of Occupational Health and Safety. Canadian Association of Oilwell Drilling Contractors: Edmonton.

Schei, Victoria 1983. Occupational Safety on Offshore Oil Structures: A Comparison of Risk Assessment and Perception in Canada and Norway. Unpublished paper. Department of Geography, University of Toronto.

Siddall, E. 1981. Risk, Fear and Public Safety. AECL-7404. April. Atomic Energy of Canada Ltd: Mississauga, Ontario.

Siddall, E. 1982. Safety Policy in the Production of Electricity. AECL-7540. September. Atomic Energy of Canada Ltd: Mississauga, Ontario.

Siddall, E. 1983. The Safety of Drilling Offshore of Eastern Canada. Unpublished paper. 7 October.

Snider, W.D., G.J. Buffleben, J.R. Harrald, K.F. Bishop and J.C. Card 1977. Management of Mid-Atlantic Offshore Development Risks in Marine Technology 14:4 (October), pp.331-50.

Solomon, K.A. and Pamela F. Nelson 1982. An Evaluation of Alternative Safety Criteria for Nuclear Power Plants. Prepared by the Rand Corporation for the Oak Ridge National Laboratory. N-1806-ORNL. June.

Starr, C. 1972 Benefit-cost studies in Sociotechnical systems in Perspectives on Benefit-Risk Decision Making National Academy of Engineering: Washington, D.C.

U.K. Committee on Offshore Safety, Burgoyne, J.H. (Chairman) 1981. Offshore Safety. Her Majesty's Stationery Office: London.

U.S. Atomic Energy Commission 1975. Reactor Safety Study. The Rasmussen Report. WASH-1400. Washington, D.C.

U.S. Department of Labor 1980. Selected Occupational Fatalities Related to Oil/Gas Well Drilling Rigs as Found in Reports of OSSA Fatality/Catastrophe Investigations. Prepared by William W. Cloe. Office of Statistical Studies and Analysis. OSSA: Washington, D.C.

U.S. National Research Council 1981. Safety and Offshore Oil. Report of the Committee on Assessment of Safety of OCS Activities. National Academy Press: Washington, D.C.

U.S. National Research Council Safety and Offshore Oil: Background Papers of the Committee on Assessment of Safety of OCS Activities. National Academy Press: Washington, D.C.

U.S. National Transportation Safety Board 1983. Safety Recommendations. M-83-8 through 23; 24-33, and 34-35 Issued Feb. 28. Washington, D.C.

U.S. National Transportation Safety Board 1983. NTSB Cites a Shattered Porthole, Electrical Malfunction, Loss of Control in Ocean Ranger Sinking in News Digest 2:2 (February 8).

Whitney, Stearns H. Drill Rig Accidents in Background Papers, Safety and Offshore Oil. See also Proceedings from the Symposium June 8-10, 1983, La Jolla, California. Industrial Association of Drilling Contractors: Houston, Texas.

Whyte, Anne V. and Ian Burton (Eds.) 1980. Environmental Risk Assessment. Scope 15. John Wiley and Sons: Chichester.

Whyte, A.V. and Ian Burton 1982. Perception of Risks in Canada in Living with Risk: Environmental Risk Management in Canada by I. Burton, C.D. Fowle and R.S. McCullough (eds.). Environmental Monograph 3, Institute for Environmental Studies, University of Toronto: Toronto.

Whyte, A.V. 1983. Probabilities, Consequences and Values in the Perception of Risk in Risk: Proceedings of a Royal Society Symposium on the Assessment and Perception of Risk by J.T. Rogers and D.V. Bates (eds.). Royal Society of Canada: Ottawa.

World Wide Offshore Accidents Databank Det norske Veritas: Oslo.